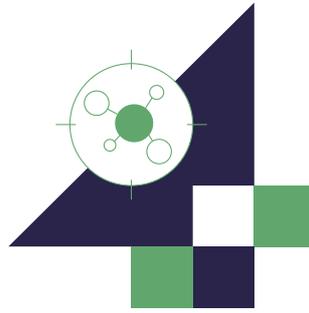# National Science and Mathematics Olympiad

Learning Materials for the Science Track

National Teams Competition 2026

Science

Biology

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Vertebrate Physiology

Introduction

Vertebrate physiology is one of the fundamental branches of biology, concerned with the study of the vital functions of the systems and organs of vertebrate organisms such as humans and animals. The importance of this science lies in its explanation of how different organs work together to maintain homeostasis and ensure the continuation of life.

Understanding the mechanisms of the vertebrate body—such as respiration, circulation, excretion, digestion, and the nervous and muscular systems—helps explain biological phenomena, develop medical and veterinary applications, improve animal production, and enhance basic scientific knowledge about the nature of life.

General objectives:

1. To identify the functional basis of vertebrate organs and systems.
2. To understand the mechanisms of regulation and integration between vital systems in the body of a living organism.
3. To apply physiological concepts in medical, veterinary, and research fields.
4. Develop the ability to analyze various physiological phenomena in vertebrates.

Specific objectives:

1. Study the functions of body systems such as the nervous, digestive, circulatory, respiratory, excretory, and reproductive systems.
2. Identify physiological differences between vertebrate species (fish, amphibians, reptiles, birds, and mammals.
3. Explain the relationship between the anatomical structure and physiological function of each system.
4. Train students to conduct physiological experiments and analyze their results scientifically.
5. Relate physiological concepts to everyday life and practical applications in the fields of health, agriculture, and the environment.

Chapter One:

Organization of the Vertebrate Body
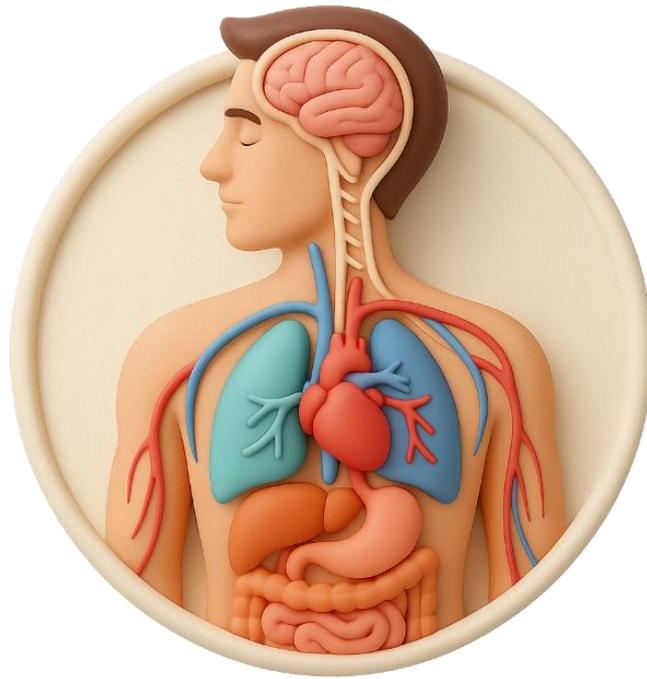
Levels of Organization in the Vertebrate Body

The organization of the vertebrate body follows a hierarchical structure, progressing from simple units to complex systems. It consists of **four main levels:**

1- Cells and Tissues

- Cells: The basic unit of life. The body of a vertebrate animal consists of hundreds of specialized cell types (about 210 types in humans).

- Tissues: Groups of cells similar in structure and function. All tissues develop during embryonic growth from three primary germ layers:

1. Ectoderm (outer layer)
2. Mesoderm (middle layer)
3. Endoderm (inner layer)

In adult animals, there are four main types of tissues: epithelial, connective, muscular, and nervous.

2. Organs and Organ Systems

- Organs: Structural and functional units composed of different tissue types working together. Example: The heart is made up of muscular, connective, epithelial, and nervous tissues.

- Organ Systems: Groups of organs that work together to perform major vital functions. Example: The circulatory system, which includes the heart and blood vessels. The vertebrate body has 11 major organ systems.
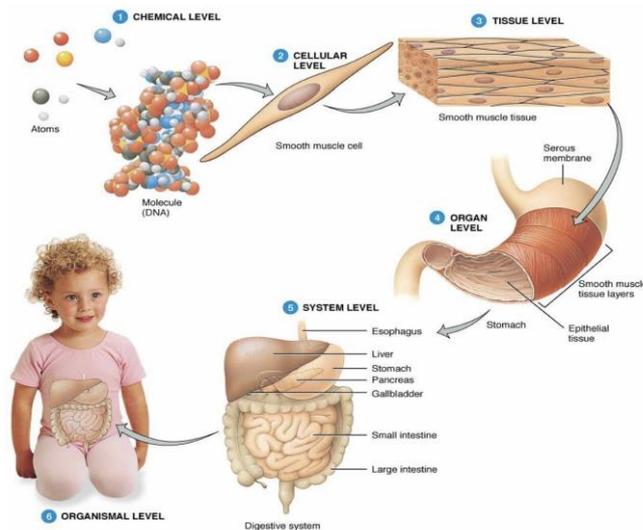
Figure 1 Levels of Organization in the Vertebrate Body

3. General Body Plan and Cavities

Vertebrates are characterized by a specific and well-defined general body plan and structural organization:

- Tube-within-a-tube body plan: The body consists of an outer main tube supported by an internal skeleton, enclosing an inner tube — the digestive tract.
- Body cavities: The vertebrate body is divided into two main cavities:
  o Dorsal cavity: Includes the skull and vertebral column.
  o Ventral cavity: In mammals, this is divided by the diaphragm muscle into two parts:
    ▪ The thoracic cavity, which contains the heart and lungs.
    ▪ The abdominopelvic cavity, which contains the organs of digestion and excretion.

These cavities are remnants of the coelom, an embryonic cavity derived from the mesoderm layer. In adult vertebrates, the coelom becomes partitioned into specialized membranes surrounding internal organs—such as the peritoneal cavity around abdominal organs, the pericardial cavity around the heart, and the pleural cavities around the lungs.

Epithelial Tissue

Epithelial tissue is defined as the tissue that covers all external body surfaces and lines internal cavities and organs. It arises from all three germ layers (ectoderm, mesoderm, and endoderm) and also forms the functional units of glands.

Main Characteristics and Functions:

1. Barrier Function: Acts as a selective barrier that regulates the movement of substances between the external environment and internal organs. It protects against dehydration and pathogens (as in the skin), allows selective nutrient absorption (as in the intestines), and permits rapid gas exchange (as in the lungs).

2. Cellular Cohesion: Epithelial cells are tightly bound together, minimizing intercellular spaces and reinforcing their barrier role.

3. Polarity: Epithelial cells have distinct surfaces:
   o The apical surface, which faces the cavity or external environment.
   o The basal surface, which rests on a specialized fibrous layer called the basement membrane, anchoring the epithelium to the underlying connective tissue.

4. Regenerative Capacity: Epithelial tissue has a remarkable ability to divide and regenerate continuously—essential for surfaces exposed to wear or damage. For example, the skin renews approximately every two weeks, while the stomach lining regenerates every 2–3 days.

Classification of Epithelial Tissues

Epithelial tissue is classified based on the number of cell layers and the shape of the cells in the surface layer.
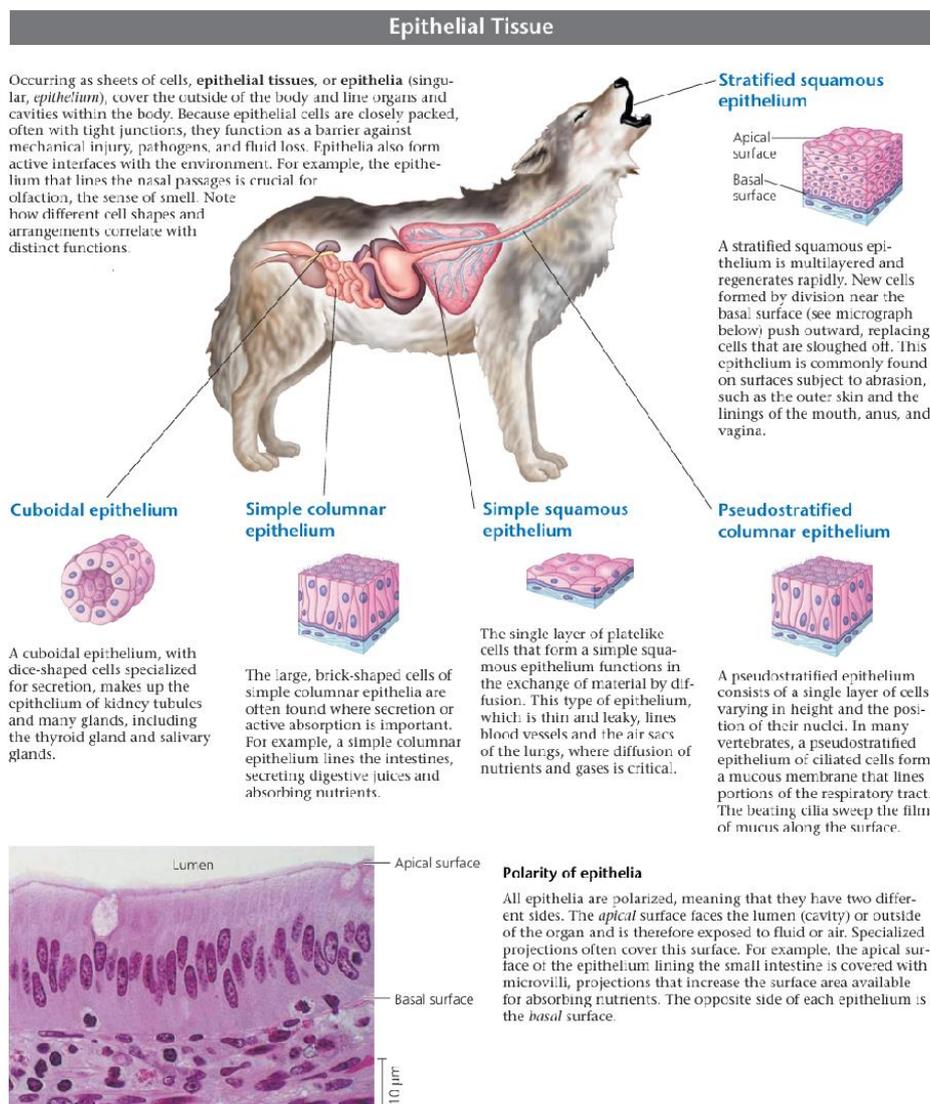
Figure 2 Types of Epithelial Tissues

Glands

Specialized structures of epithelial tissue whose function is secretion.

- **Exocrine Glands:** Retain their connection to the epithelial surface through ducts and release their products (such as sweat and saliva) onto the body surface or into its cavities.

- **Endocrine Glands:** Lose their connection to the surface and secrete their products (hormones) directly into the bloodstream.

Connective Tissues

Connective tissues are derived from the embryonic mesoderm layer and are distinguished from other tissues by the presence of an abundant extracellular matrix that separates their widely spaced cells. This matrix consists of protein fibers and a ground substance, whose consistency varies from fluid (as in blood) to solid (as in bone), giving each tissue its unique characteristics. Connective tissues are broadly classified into two main groups:

1. Connective Tissue Proper

In this type, fibroblasts (fiber-producing cells) generate the extracellular matrix. It is further divided into subtypes depending on fiber arrangement and density.

LOOSE CONNECTIVE TISSUE
Typical Location
Beneath skin; between organs
Function
Provides support, insulation, food storage, and nourishment for epithelium
Characteristic Cell Types
Fibroblasts, macrophages, mast cells, fat cells

DENSE CONNECTIVE TISSUE
Typical Location
Tendons; sheath around muscles; kidney; liver; dermis of skin
Function
Provides flexible, strong connections
Characteristic Cell Types
Fibroblasts

CARTILAGE
Typical Location
Spinal discs; knees and other joints; ear; nose; tracheal rings
Function
Provides flexible support, shock absorption, and reduction of friction on load-bearing surfaces
Characteristic Cell Types
Chondrocytes

Figure 3 Types of Connective Tissue Proper

▣ 2. Specialized Connective Tissue

Despite their tremendous diversity in form and function, all connective tissues share a common embryonic origin (the mesoderm) and a fundamental structure composed of scattered cells embedded within an extracellular matrix.

BONE
Typical Location
Most of skeleton
Function
Protects internal organs; provides rigid support for muscle attachment
Characteristic Cell Types
Osteocytes

BLOOD
Typical Location
Circulatory system
Function
Functions as highway of immune system and primary means of communication between organs
Characteristic Cell Types
Erythrocytes, leukocytes
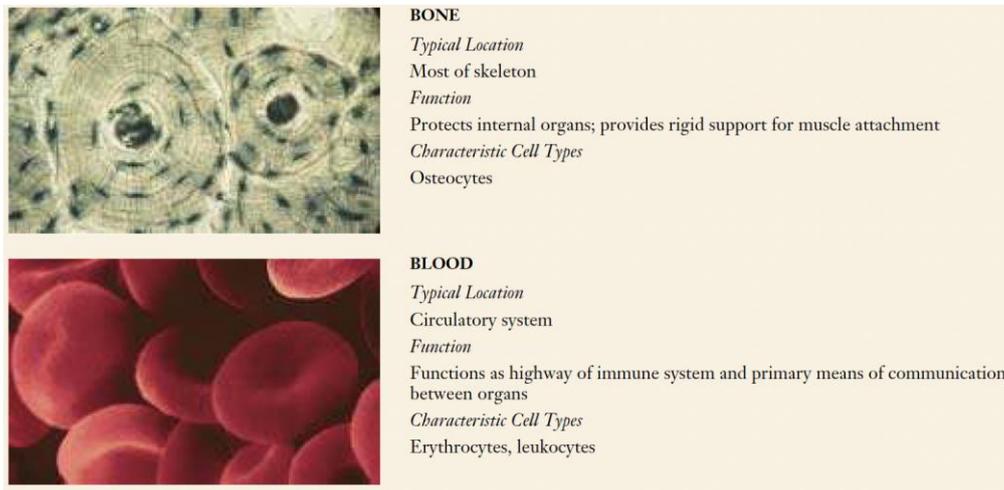
Figure 4 Types of Specialized Connective Tissues

Muscle Tissue

Muscle tissue is responsible for movement in the bodies of vertebrates. Its cells are characterized by an abundance and precise organization of the protein filaments actin and myosin, which give them a specialized ability to contract. Vertebrates possess three main types of muscles. These three types perform distinct vital functions: smooth muscles carry out the functions of internal organs, skeletal muscles move the body, and cardiac muscles form the muscular pump of the heart.

SMOOTH MUSCLE
Typical Location
Walls of blood vessels, stomach, and intestines
Function
Powers rhythmic, involuntary contractions commanded by the central nervous system
Characteristic Cell Types
Smooth muscle cells

SKELETAL MUSCLE
Typical Location
Voluntary muscles
Function
Powers walking, lifting, talking, and all other voluntary movement
Characteristic Cell Types
Skeletal muscle cells

CARDIAC
Typical Location
Walls of heart
Function
Highly interconnected cells; promotes rapid spread of signal initiating contraction
Characteristic Cell Types
Cardiac muscle cells

Nuclei

Nuclei

Nuclei

Intercalated discs

Figure 5 Types of Muscle Tissues

Nervous Tissue

Nervous tissue constitutes the fourth main type of tissue in vertebrates and is responsible for coordination and communication within the body. This tissue consists of two main types of cells: neurons, which are the basic functional units, and neuroglia, which provide support and protection.
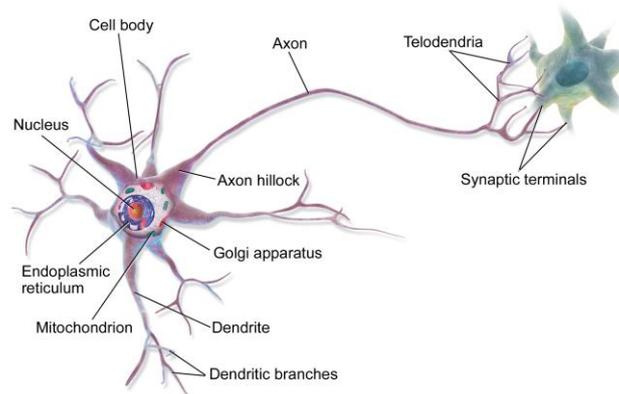
Figure 6 Structure of the Neuron

1. Organization of the Nervous System

The nervous system is divided into two main parts:

- **Central Nervous System (CNS):** Consists of the brain and spinal cord. Its function is to process and integrate information received from the body and issue commands.
- **Peripheral Nervous System (PNS):** Consists of nerves (bundles of axons) and ganglia (clusters of neuron cell bodies). Its function is to transmit signals between the central nervous system and the rest of the body, such as muscles and gland

Chapter Two

The Skeletal System

Types of Skeletal Structures

Divisions in Vertebrates:

- o Axial Skeleton: Includes the skull, vertebral column, ribs, and sternum.
- o Appendicular Skeleton: Includes the bones of the limbs and the pectoral and pelvic girdles.
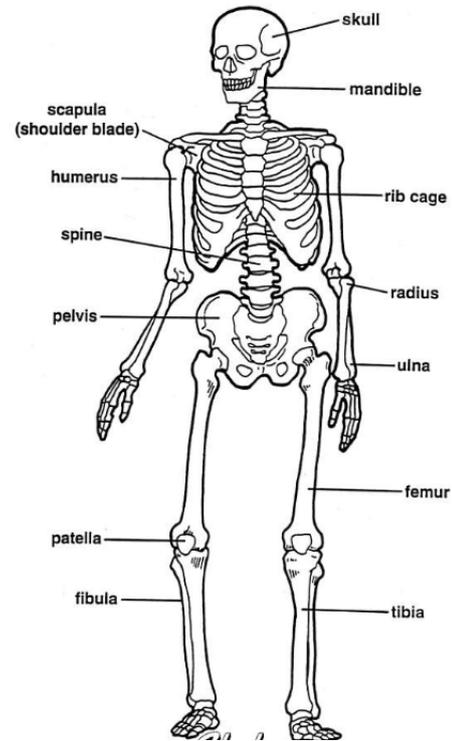
Figure 7 Skeletal Structure

Overview of Bone in Vertebrates

Bone is a living, dynamic connective tissue that undergoes continuous processes of formation, growth, and remodeling.

A. Ossification:

- Intramembranous Ossification: In this process, bones (such as flat skull bones) form directly within layers of connective tissue. Osteoblasts (bone-forming cells) secrete hydroxyapatite crystals (calcium phosphate) onto collagen fibers.

- Endochondral Ossification: Most bones (such as long limb bones) develop by replacing a pre-existing cartilage model with living bone tissue.

B. Structure of Bone:

- Cells: Bone tissue consists of osteoblasts (bone-forming cells), osteocytes (mature bone cells embedded within the solid matrix), and osteoclasts (bone-resorbing cells responsible for remodeling).

Figure 8 Internal Structure of a Long Bone

- Types: Classified into compact (dense) bone on the exterior and spongy bone on the interior.

- Haversian System: In compact bone, cells are arranged in concentric rings around Haversian canals, which contain blood vessels and nerves, keeping the tissue alive.

C. Bone Remodeling

Bone responds to mechanical stress. Repeated forces (such as physical exercise) generate a piezoelectric effect in the hydroxyapatite crystals, stimulating osteoblasts to increase bone density and strength.

Movement occurs at joints, which are the points where bones meet.

- Types of Joints: Joints are classified into: Immovable joints (such as the sutures of the skull)– Slightly movable joints (between the vertebrae)– Freely movable joints (synovial joints) such as the knee and hip
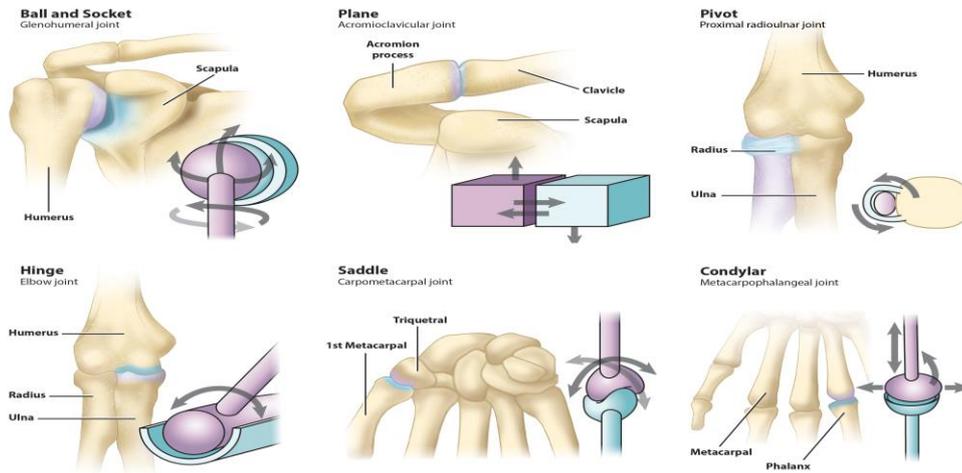
Figure 9 Types of Joints in the Skeletal System

- Muscle Action: Muscles attach to bones through tendons. Each muscle has an origin (the fixed attachment point) and an insertion (the movable attachment point).

Muscles work in antagonistic pairs:

- The agonist (prime mover) produces the movement.
- The antagonist opposes or reverses that movement.

Muscle contraction occurs at the molecular level according to the Sliding Filament Theory.

A. Microscopic Structure

A muscle fiber is composed of myofibrils, which in turn consist of repeating units called sarcomeres. Each sarcomere contains two types of filaments:

Figure 10 Microscopic Structure of Skeletal Muscle

- Thick filaments: Made of the protein myosin, which has movable heads.
- Thin filaments: Composed mainly of the protein actin.

B. Cross-Bridge Cycle

1. Attachment: The myosin head (activated by ATP) binds to an active site on the actin filament, forming a cross-bridge.
2. Power Stroke: The myosin head pivots, pulling the actin filament toward the center of the sarcomere, shortening it and producing contraction.
3. Detachment: A new ATP molecule binds to the myosin head, causing it to detach from actin.
4. Reactivation: The ATP is hydrolyzed, re-cocking the myosin head and preparing it for another cycle.The cycle repeats continuously as long as the muscle is stimulated.
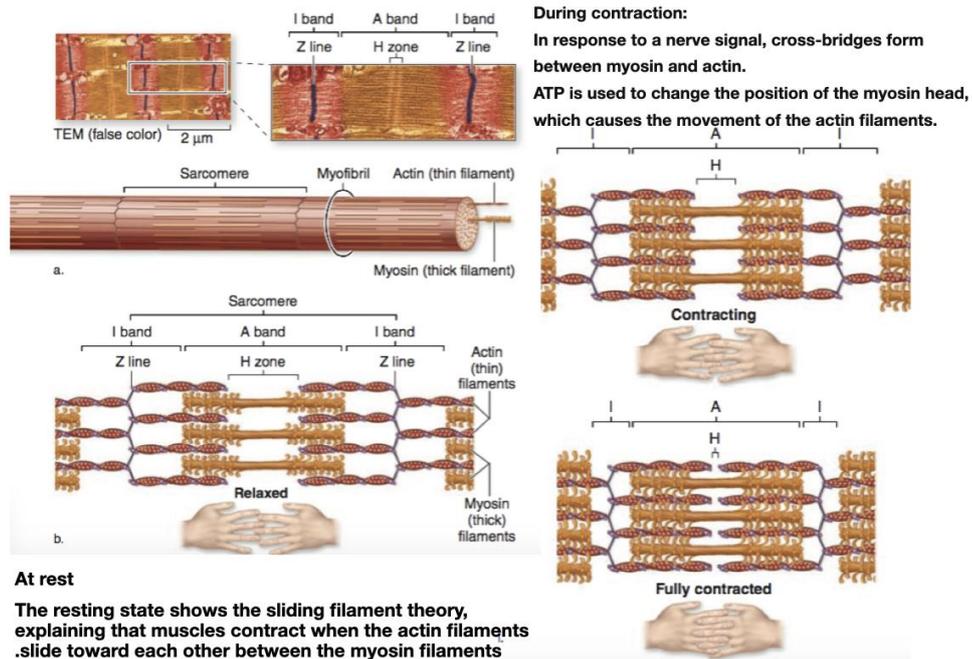
Figure 11 Mechanism of Myofibril Contraction (Sliding Filament Theory)

C. Role of Calcium in Regulation

- In the resting state, the proteins tropomyosin and troponin located on the actin filament block the myosin binding sites.

- When a nerve impulse arrives, calcium ions (Ca^{2+}) are released from the sarcoplasmic reticulum.

- Calcium binds to the troponin protein, causing a change in its shape that moves tropomyosin away, exposing the myosin-binding sites. This allows the cross-bridge cycle to begin, leading to muscle contraction
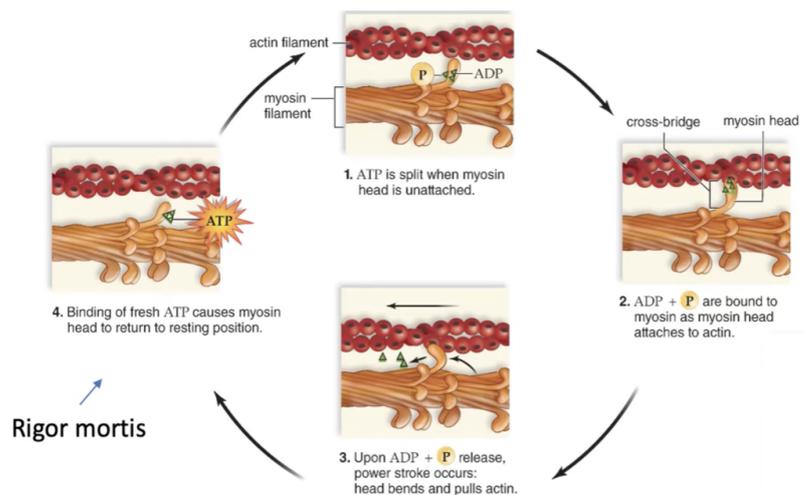
Figure 12 Cross-Bridge Cycle in Muscle Contraction

D. Types of Muscle Fibers

- Slow-Twitch Fibers (Red): Rich in mitochondria and myoglobin, rely on aerobic respiration, and are characterized by high endurance and fatigue resistance.
- Fast-Twitch Fibers (White): Depend on anaerobic respiration and glycogen reserves, contract rapidly and powerfully, but fatigue quickly.

Patterns of Animal Movement

Modes of movement vary depending on the environment, but the physical principles governing them remain the same.

- Movement in Water: The main challenge is drag (friction). Animals overcome it through jet propulsion (as in squid), undulating body movements (as in fish), or by using limbs like paddles (as in ducks and turtles).
- Movement on Land: The primary challenge is gravity. Limbs evolved for support and propulsion. Increasing the number of legs (as in arthropods) enhances stability but may reduce speed, while four limbs (in vertebrates) allow for fast movements such as running and jumping.
- Flight: Evolved independently four times (in insects, pterosaurs, birds, and bats). Flight depends on generating lift by pushing air downward with the wings and utilizing the pressure difference between the upper and lower wing surfaces
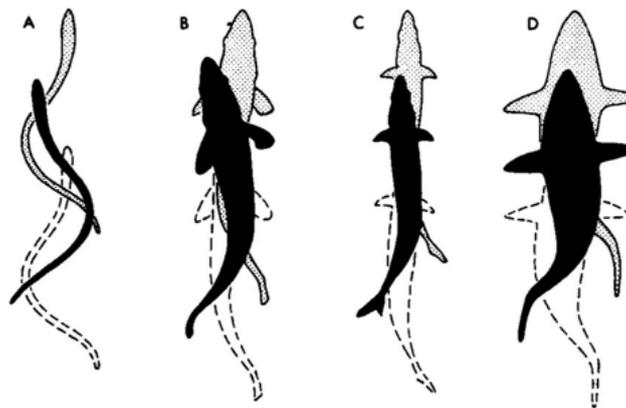
. Gradation of swimming modes from (A) anguilliform, through (B) subcaran-giform, and (C) carangiform, to (D) thunniform.

Figure 13 Propulsion and Locomotion Mechanism in Fish

Chapter Three

The Nervous System

Basic Organization of the Nervous System

The nervous system functions as a rapid communication and control network. It gathers information, processes it, and issues commands to maintain homeostasis and respond to stimuli. It consists of specific structural and functional units.

A. Types of Neurons:

1. Sensory Neurons (Afferent): Transmit information from sensory receptors (such as the skin and eyes) to the central nervous system.

2. Motor Neurons (Efferent): Carry commands from the central nervous system to effector organs (muscles and glands).

3. Interneurons (Associative): Found within the central nervous system; they process information and connect sensory and motor neurons. They form the basis of complex functions such as learning and memory.
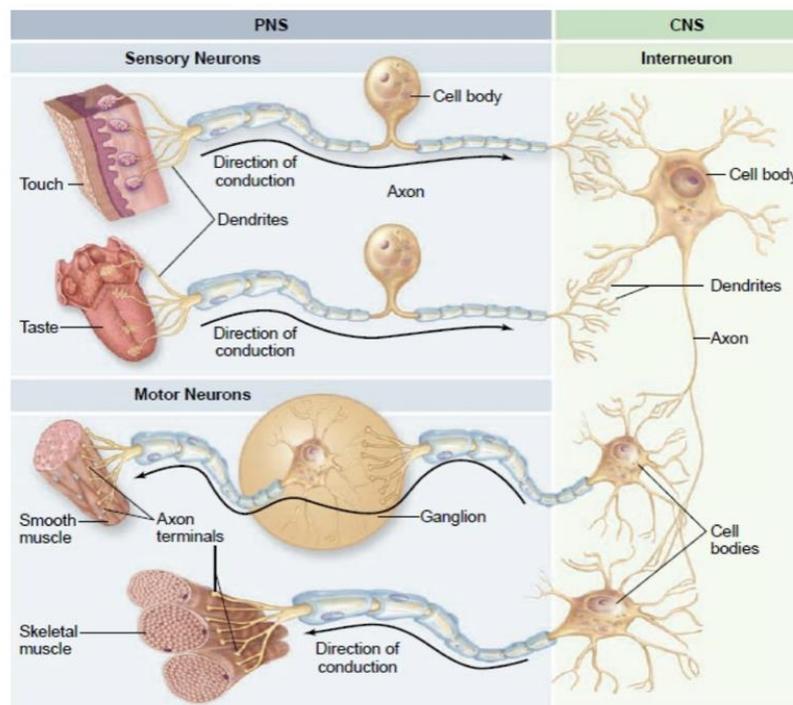
Figure 14 Types of Neurons in the Central and Peripheral Nervous Systems

B. Divisions of the Nervous System

- Central Nervous System **(CNS):** The control center of the body, consisting of the brain and the spinal cord.

- Peripheral Nervous System **(PNS):** Composed of nerves and ganglia located outside the central nervous system. It functions as a communication network linking the CNS with the rest of the body.

The Neuron (Nerve Cell):

It is the structural and functional unit of the nervous system, characterized by a unique structure that supports its function.

A. Structure of the Neuron

- Cell Body: Contains the nucleus.
- Dendrites: Branched extensions that receive signals from other neurons.
- Axon: A single long projection that transmits nerve impulses away from the cell body.

B. Supporting Cells (Neuroglia or Glial Cells)

These are non-neuronal cells that outnumber neurons and provide essential support.

- Function: Supply nutrients, remove waste products, and provide structural support to neurons.
- Myelin Sheath: A fatty insulating layer that wraps around axons. It is produced by Schwann cells in the peripheral nervous system

Figure 16 Formation of the Myelin Sheath Around the Axon

and oligodendrocytes in the central nervous system. This sheath greatly increases the speed of nerve impulse transmission.

- Nodes of Ranvier: Unmyelinated gaps along the myelinated axon where the nerve impulse "jumps" from one node to another in a process known as saltatory conduction.

The Nerve Impulse: The Language of the Nervous System

Neurons communicate through electrical signals generated by the movement of ions across their plasma membrane.

A. Resting Potential

When a neuron is not stimulated, it maintains an electrical potential difference across its membrane of about **–70 millivolts (mV)**, with the inside of the cell being negative relative to the outside. This potential arises due to:

1. Sodium–Potassium Pump: Actively transports three sodium ions (Na^+) out of the cell for every two potassium ions (K^+) pumped in.
2. Leak Channels: A large number of potassium leak channels remain open, allowing positive charges to leave the cell continuously.

◻ B. Action Potential

An action potential is a rapid and temporary change in membrane potential that constitutes the nerve impulse. It is an **"all-or-none"** event.

1. Depolarization (Rising Phase): When a sufficient stimulus reaches the threshold potential (around −55 mV), voltage-gated sodium channels open, and Na^+ rushes into the cell, reversing the charge inside to positive.

2. Repolarization (Falling Phase): Sodium channels close, and voltage-gated potassium channels open, allowing K^+ to flow out of the cell, restoring the negative internal charge.

3. The action potential propagates as a self-renewing wave of excitation along the axon to its terminal.
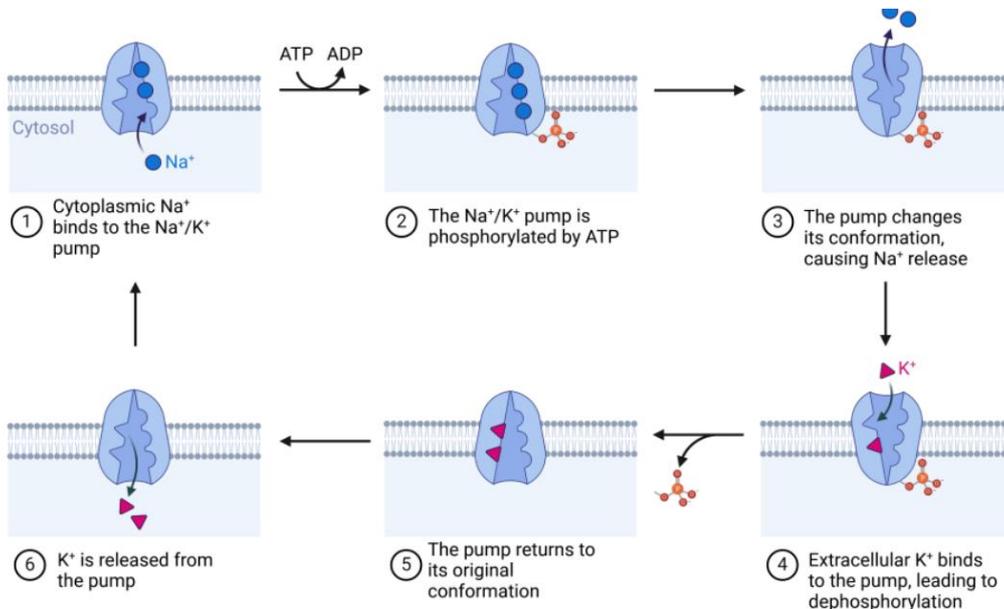
Figure 17 Mechanism of the Sodium–Potassium Pump in the Cell Membrane

The Synapse: The Point of Connection

A synapse is the junction between one neuron and another, or between a neuron and an effector cell (muscle or gland).

- Electrical Synapse: Rare in vertebrates; the signal is transmitted directly through gap junctions.

- Chemical Synapse: The most common type, where the electrical signal is converted into a chemical signal.
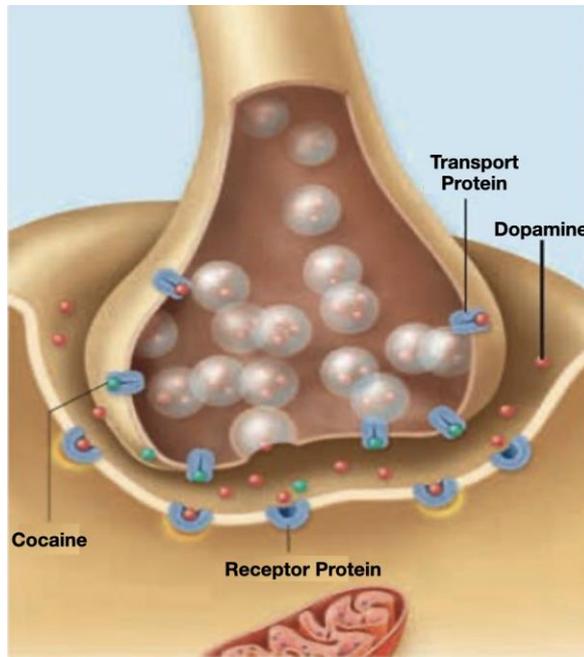
Figure 18 : Structure of the Synaptic Junction

▣ **Mechanism of Chemical Synaptic Transmission:**

1. The action potential reaches the end of the axon terminal.
2. Voltage-gated calcium channels (Ca^{2+}) open, allowing calcium ions to enter.
3. Calcium triggers synaptic vesicles to fuse with the membrane and release neurotransmitters into the synaptic cleft.
4. The neurotransmitters bind to receptors on the postsynaptic membrane, causing a response — either excitatory or inhibitory.

▣ **Synaptic Integration:**

A single neuron receives thousands of excitatory and inhibitory signals simultaneously. It integrates these signals (spatial and temporal summation), and if the combined input reaches the threshold potential, the neuron generates an action potential.
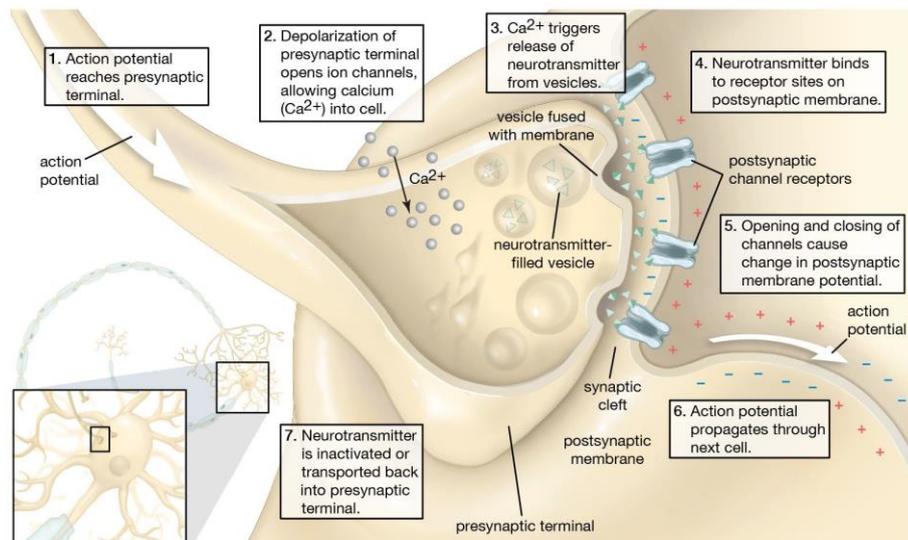
Figure 19 Mechanism of Nerve Impulse Transmission Across the Synapse

The Central Nervous System (Brain and Spinal Cord)

A. The Brain

The brain is the center for information processing and higher control. It has evolved greatly in vertebrates, especially the forebrain, which has become dominant.

- Cerebrum: The largest part of the human brain, responsible for higher functions. Its outer surface, the cerebral cortex, is the site of consciousness, thought, language, and memory.
- Cerebellum: Coordinates voluntary movements and maintains balance.
- Brainstem: Regulates vital functions such as breathing and heart rate.

B. The Spinal Cord

Extends from the brain through the vertebral column.

- **Function:** Acts as a main communication pathway between the brain and the body, and serves as a control center for reflexes, which are fast and involuntary actions.

The Peripheral Nervous System (PNS)

Consists of nerves that connect the central nervous system to the rest of the body.

A. Somatic Nervous System

- Function: Controls voluntary movements of skeletal muscles.

B. Autonomic Nervous System

- Function: Regulates involuntary functions of internal organs (such as the heart, blood vessels, and glands).

- Sympathetic Division: Prepares the body for emergencies — the "fight or flight" response.

- Parasympathetic Division: Dominates during rest — the "rest and digest" response. The two divisions work in opposite yet complementary ways.
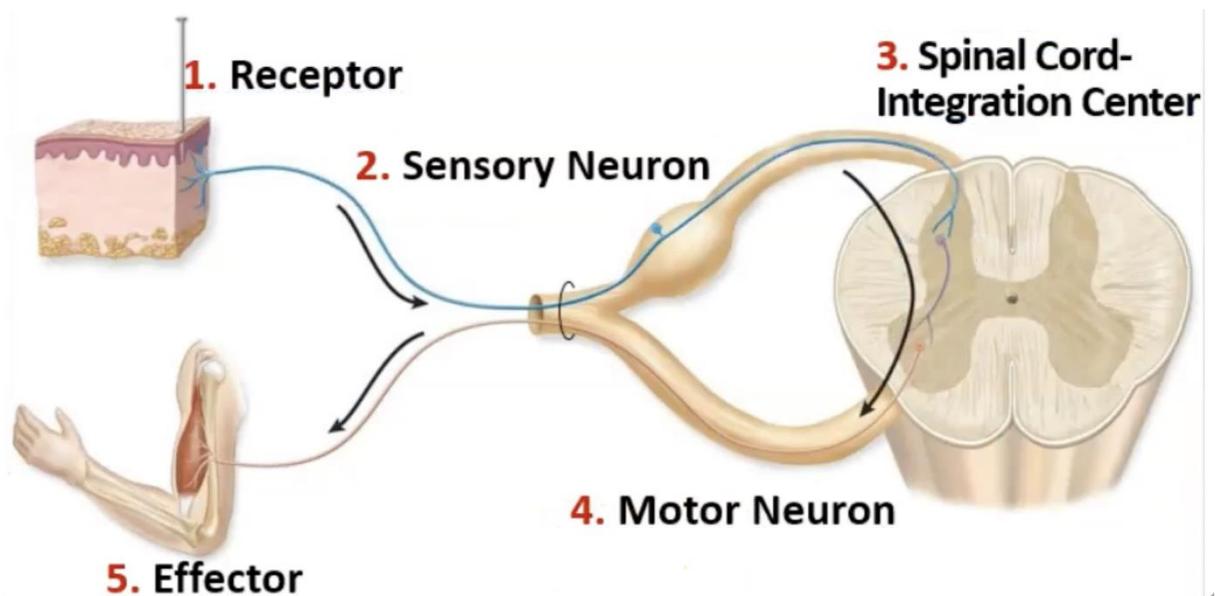
Figure 20 Structure of the Spinal Cord and the Pathway of Nerve Impulses Between the Skin and Muscles

The parasympathetic and sympathetic divisions of the autonomic nervous system. Most pathways in each division involve two neurons. The axon of the first neuron extends from a cell body in the CNS to a set of PNS neurons whose cell bodies are clustered into a ganglion (plural, *ganglia*). The axons of these PNS neurons transmit instructions to internal organs, where they form synapses with smooth muscle, cardiac muscle, or gland cells.

Parasympathetic division

Action on internal organs:
- Constricts pupil of eye
- Stimulates salivary gland secretion
- Constricts bronchi in lungs
- Slows heart
- Stimulates activity of stomach and intestines
- Stimulates activity of pancreas
- Stimulates gallbladder
- Promotes emptying of bladder
- Promotes erection of genitalia

Cervical
Thoracic
Lumbar
Sacral
Synapse
Sympathetic ganglia

Sympathetic division

Action on internal organs:
- Dilates pupil of eye
- Inhibits salivary gland secretion
- Relaxes bronchi in lungs
- Accelerates heart
- Inhibits activity of stomach and intestines
- Inhibits activity of pancreas
- Stimulates glucose release from liver; inhibits gallbladder
- Stimulates adrenal medulla
- Inhibits emptying of bladder
- Promotes ejaculation and vaginal contractions

Figure 21 Effects of the Sympathetic and Parasympathetic Nervous Systems on Body Organs

Chapter Four

The Digestive System
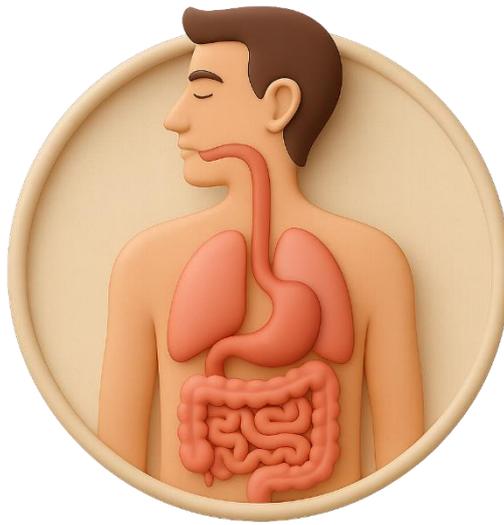
Principles of Digestion and Feeding Types

Digestion is the process of breaking down large, complex food molecules into small, absorbable building units. Animals are classified according to their food sources into:

- **Herbivores:** Feed on plants.
- **Carnivores:** Feed on other animals.
- **Omnivores:** Feed on both plants and animals.

Digestion occurs either intracellularly (as in sponges) or extracellularly within a digestive cavity, which is the predominant method in most animals. The digestive system takes two main structural forms:

1. Gastrovascular Cavity: A simple digestive system with a single opening that functions as both mouth and anus (e.g., cnidarians).

2. Digestive Tract (Alimentary Canal): A specialized tube extending from the mouth to the anus, allowing each region to specialize in a particular function such as digestion, absorption, or storage.
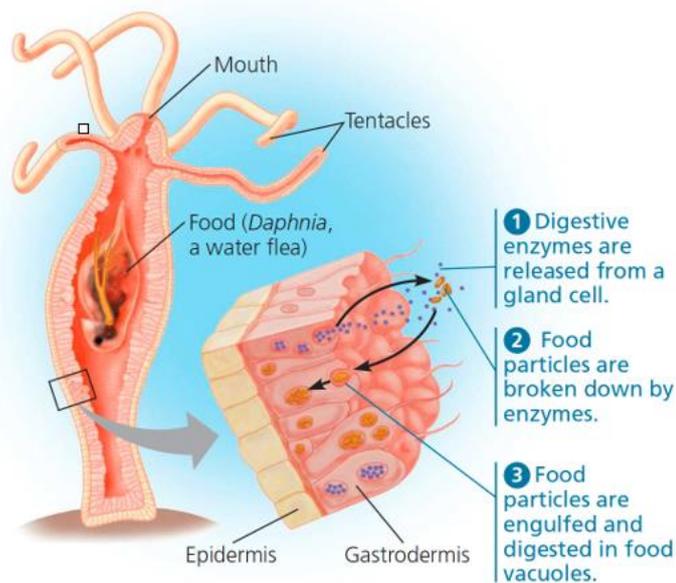
Figure 22 Anatomical Structure of Hydra and Its Feeding Mechanism

The vertebrate digestive system consists of a tubular canal and accessory organs, and the process of digestion proceeds through several sequential stages.

A. Mouth and Teeth

- **Function:** Digestion begins here with the mechanical breakdown of food by the teeth (chewing) and the chemical digestion of starch by saliva, which contains the enzyme salivary amylase.

- **Tooth Adaptations:** The shape of teeth reflects the animal's diet — carnivores have sharp canines for tearing, herbivores have flat molars for grinding, while humans possess a combination of both types.

- **Swallowing:** A coordinated process that begins voluntarily and then becomes involuntary. The tongue pushes food into the pharynx, while the epiglottis closes the airway to prevent food from entering the respiratory tract.
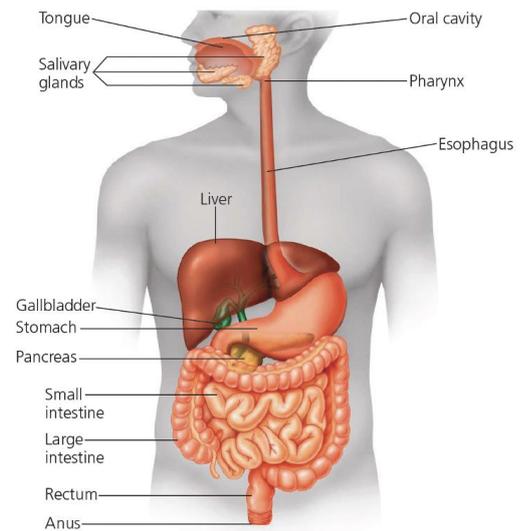
Figure 23 Anatomical Structure of the Human Digestive System

B. Esophagus and Stomach

- **Esophagus:** A muscular tube that transports food from the pharynx to the stomach through rhythmic contractions called peristalsis.

- **Stomach:** A muscular sac that stores, mixes, and begins the digestion of proteins.
  - **Gastric Juice:** Contains hydrochloric acid (HCl), which kills microbes and denatures proteins, and pepsinogen, which is converted in the acidic
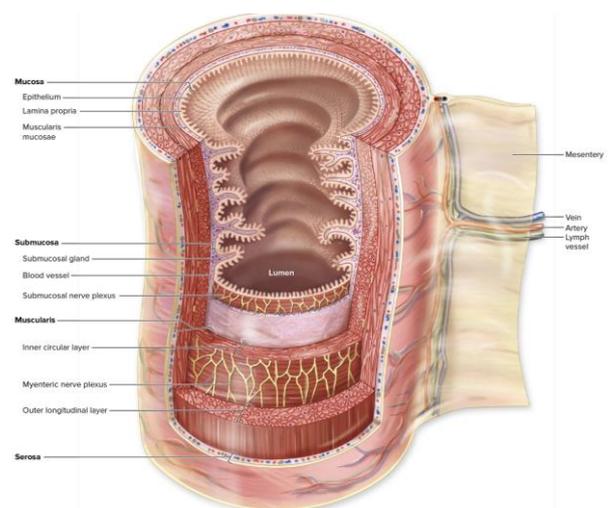
Figure 24 Anatomical Structure of the Gastrointestinal Tract Wall

environment to pepsin, the active enzyme that digests proteins.

- Chyme: A semi-liquid mixture of partially digested food and gastric secretions.
- Gastric Ulcers: Often associated with infection by the bacterium *Helicobacter pylori*.
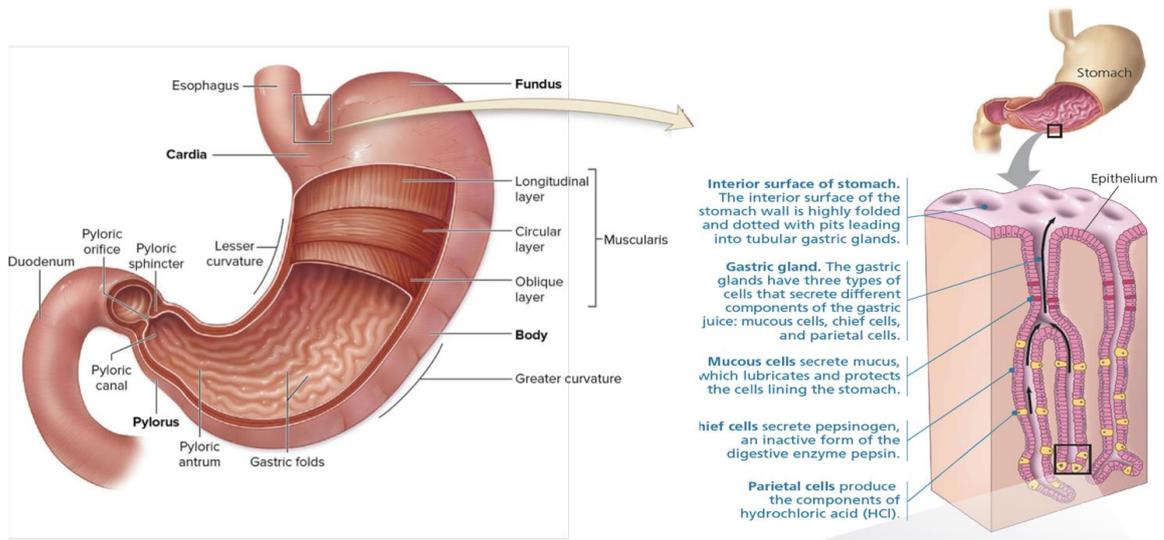
Figure 25 Internal Structure of the Stomach Wall and Gastric Glands

C. Small intestine

The small intestine is the main site for completing digestion and absorbing most nutrients.

- Structure: It consists of three parts — the duodenum, jejunum, and ileum. Its inner wall contains folds covered with finger-like projections called villi, which are themselves lined with microvilli. These structures greatly increase the surface area for absorption — up to about 300 square meters in humans.
- Function:
  1. Completion of Digestion: The small intestine receives secretions from the pancreas and liver, as well as brush border enzymes located on the microvilli, which complete the digestion of carbohydrates, proteins, and fats.
  2. Absorption: Monosaccharides and amino acids are absorbed into the bloodstream, while the products of fat digestion are assembled into chylomicrons, which enter the lymphatic system first.

- Function: The large intestine is the final section of the digestive tract, responsible for absorbing remaining water and salts, and for forming and storing feces (waste material).
- Colon Bacteria: It hosts a vast number of beneficial bacteria that ferment undigested fibers and produce essential vitamins such as vitamin K.
- Defecation: Feces are expelled through the rectum and anus, which are controlled by two sphincters — an internal (involuntary) and an external (voluntary) sphincter.

Accessory Digestive Organs

These are organs located **outside the digestive tract** but essential for the digestion process through their secretions.

- Pancreas: Secretes alkaline pancreatic juice containing powerful digestive enzymes such as trypsin (for protein digestion), amylase (for starch digestion), and lipase (for fat digestion). It also produces the hormones insulin and glucagon, which regulate blood sugar levels.
- Liver: The largest internal organ in the body. It produces bile, which emulsifies fats - breaking them down into small droplets for easier digestion. The liver also performs vital metabolic functions, including detoxification and synthesis of blood proteins.
- Gallbladder: A small sac that stores and concentrates bile produced by the liver until it is released into the small intestine.
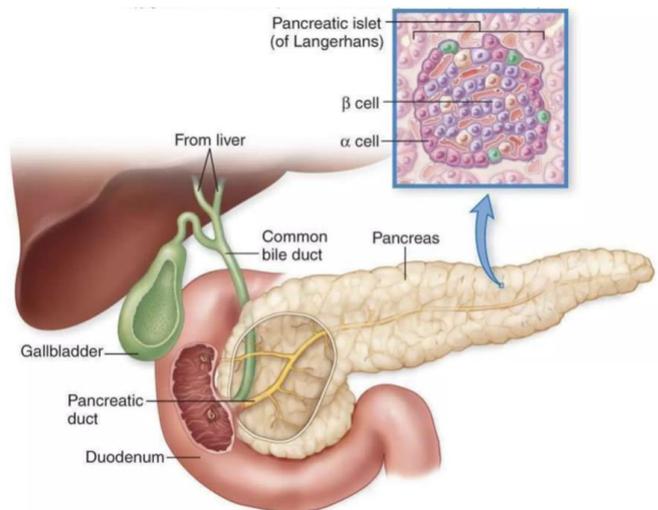
Figure 26 Anatomical Structure of the Pancreas

Specialized Digestive Adaptations in Vertebrates

Animals especially herbivores—have developed special adaptations for digesting cellulose, a major component of plant cell walls that most animals cannot digest on their own.

- Ruminants: Animals such as cows possess a complex stomach with four chambers (the largest being the rumen). Symbiotic microorganisms in the rumen ferment cellulose, breaking it down into simpler compounds. The animal then regurgitates the partially digested food (called cud) and chews it again to increase digestive efficiency.

- Cecal Digesters: Other animals, such as rabbits and horses, have an enlarged pouch called the cecum located at the junction of the small and large intestines. Microbes in the cecum ferment cellulose, aiding in digestion. Some of these animals (like rabbits) exhibit coprophagy — the behavior of re-ingesting feces to pass food through the digestive tract a second time and absorb fermentation products more effectively.

Regulation of Digestion

The process of digestion is precisely regulated by both the nervous and hormonal systems.

- Nervous Regulation: The sight, smell, or taste of food stimulates the secretion of saliva and gastric juices in preparation for digestion.

- Hormonal Regulation:
  o Gastrin: Secreted by the stomach; it stimulates the release of hydrochloric acid (HCl).
  o Secretin and Cholecystokinin (CCK): Secreted by the duodenum when acidic or fatty chyme enters from the stomach. They inhibit stomach activity while stimulating secretions from the pancreas and gallbladder.
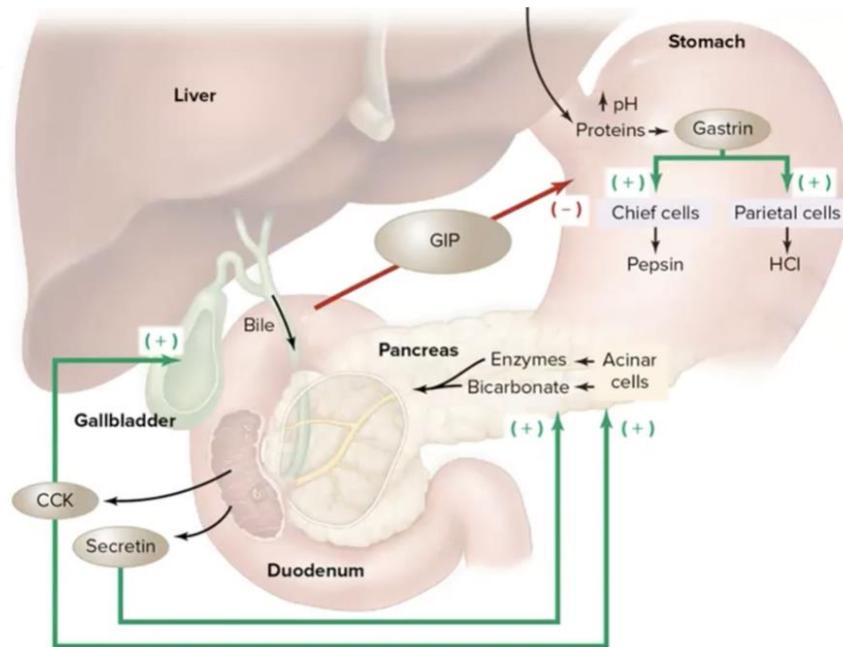
Figure 27 Hormonal Regulation of Digestive Secretions in the Digestive System

Nutrition and Energy

Food provides the body with both **energy** (measured in kilocalories) for vital activities and essential nutrients that the body cannot synthesize on its own.

- Energy Balance: When energy intake exceeds energy expenditure, the surplus is stored as fat, which may lead to obesity.

- Appetite Regulation: Controlled by a center in the hypothalamus of the brain and influenced by several hormonal signals, such as:

    o Ghrelin: Stimulates hunger.

    o Leptin and Insulin: Suppress appetite.

- Essential Nutrients: Include essential amino acids, essential fatty acids, vitamins, and minerals - all of which must be obtained through the diet to maintain proper body health.

Chapter Five

The Circulatory and Respiratory Systems
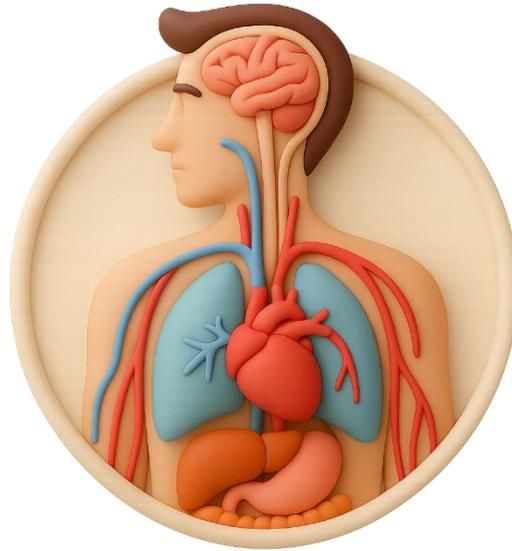
The circulatory system is the transport network responsible for distributing oxygen, nutrients, and hormones, as well as removing wastes from the body's cells. Its structural complexity ranges from simple organisms to highly developed vertebrates.

Circulation in Vertebrates

- Fish: Possess a simple two-chambered heart (one atrium and one ventricle) and a single circulatory loop. The heart pumps blood to the gills, where it is oxygenated, and then to the rest of the body before returning to the heart. A disadvantage of this system is the drop in blood pressure after passing through the gills.
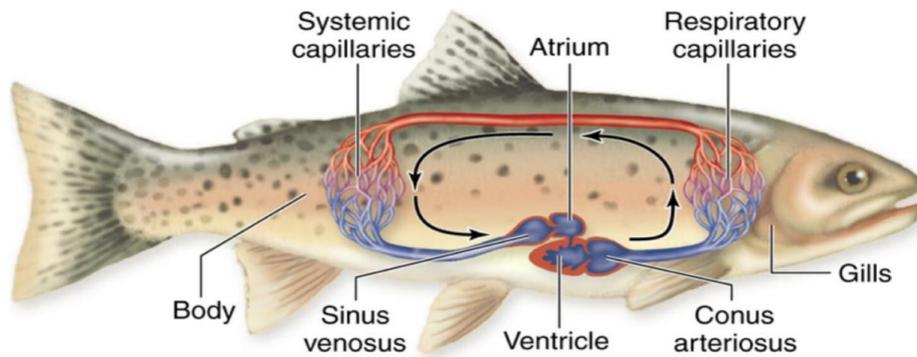
Figure 28 Circulatory System in Fish

- Amphibians and reptiles: Have a double circulatory system (pulmonary and systemic) and a three-chambered heart (two atria and one ventricle). This arrangement allows for partial separation of oxygenated and deoxygenated blood, providing higher pressure to blood flowing to the body.

- Mammals, birds, and crocodiles: Possess the most efficient system—a four-chambered heart (two atria and two completely separated ventricles). This complete separation prevents the mixing of oxygenated and deoxygenated blood, supporting the high metabolic rates required to maintain body temperature.
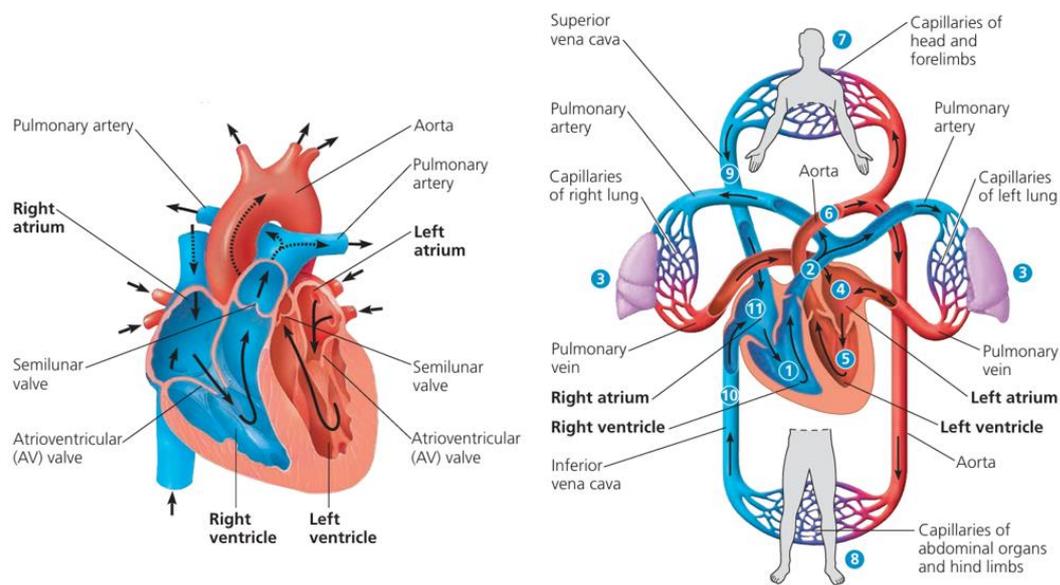
Figure 29 Diagram of Human Circulation and the Mechanism of Blood Flow Through the Heart
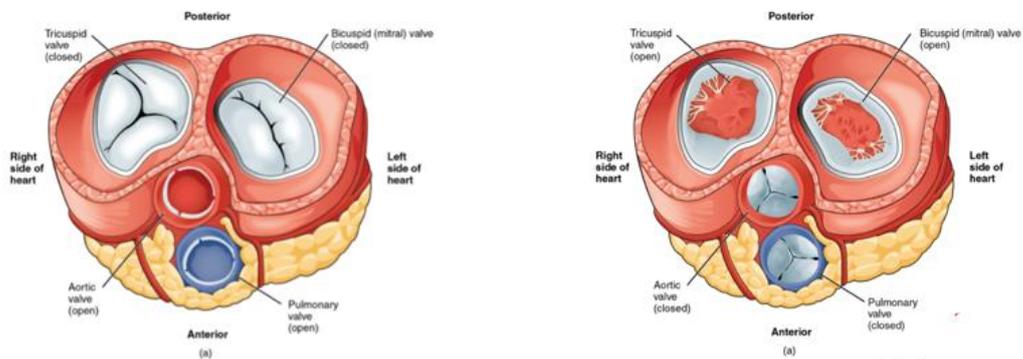
Figure 30 : Cardiac Valves in Open and Closed Positions

- **Cardiac Cycle:** The cardiac cycle is the sequence of contraction (systole) and relaxation (diastole) of the heart chambers, which together constitute a heartbeat. The characteristic "lub-dub" sounds of the heart are produced by the closure of the heart valves, which ensure that blood flows in only one direction.
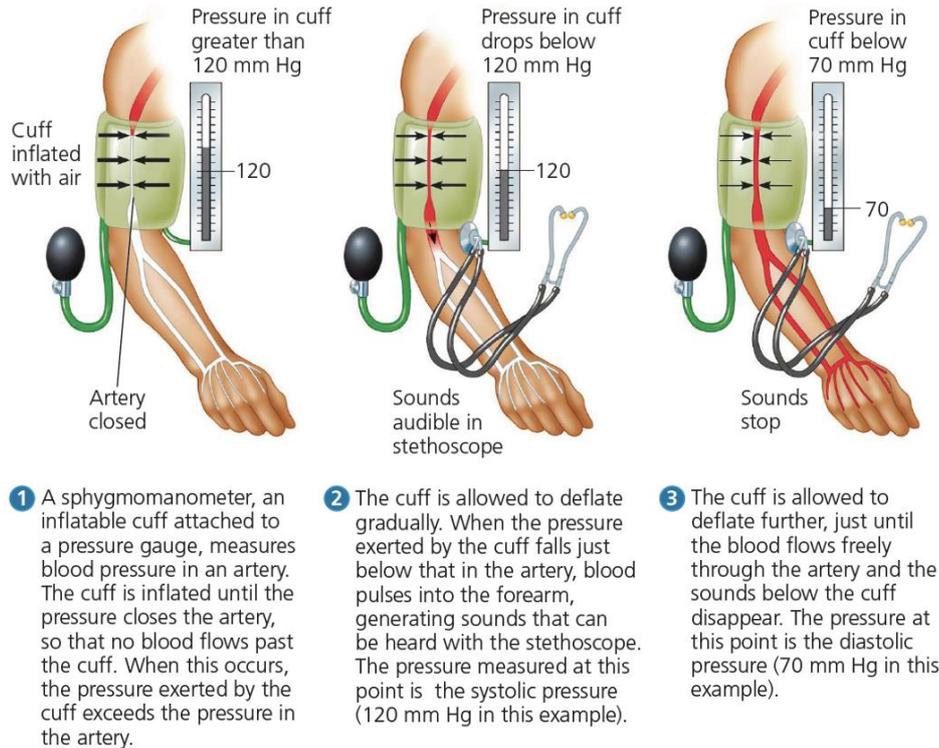
Figure 31 Steps for Measuring Blood Pressure Using a Sphygmomanometer and Stethoscope

Blood Vessels:

- Arteries: Carry blood away from the heart. They have thick, elastic walls to withstand high pressure.
- Veins: Return blood to the heart and contain valves that prevent the backflow of blood.
- Capillaries: A vast network of microscopic, thin-walled vessels that form the site of exchange of materials between the blood and body tissues.
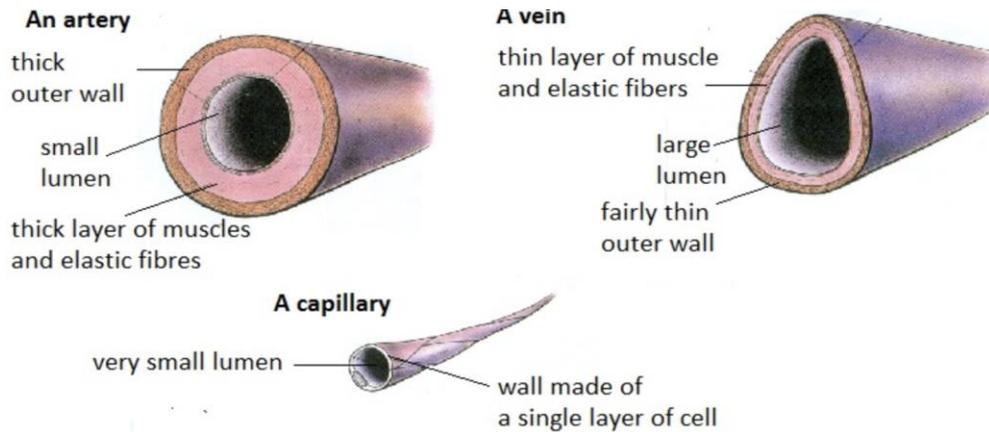
Regulation of Heartbeat and Blood Pressure:

- The heartbeat is initiated spontaneously by specialized cells in the sinoatrial (SA) node, which acts as the natural pacemaker of the heart.

- The autonomic nervous system adjusts the rate and strength of heart contractions.

- Blood pressure is maintained through a negative feedback mechanism known as the baroreceptor reflex, along with hormones that regulate blood volume.
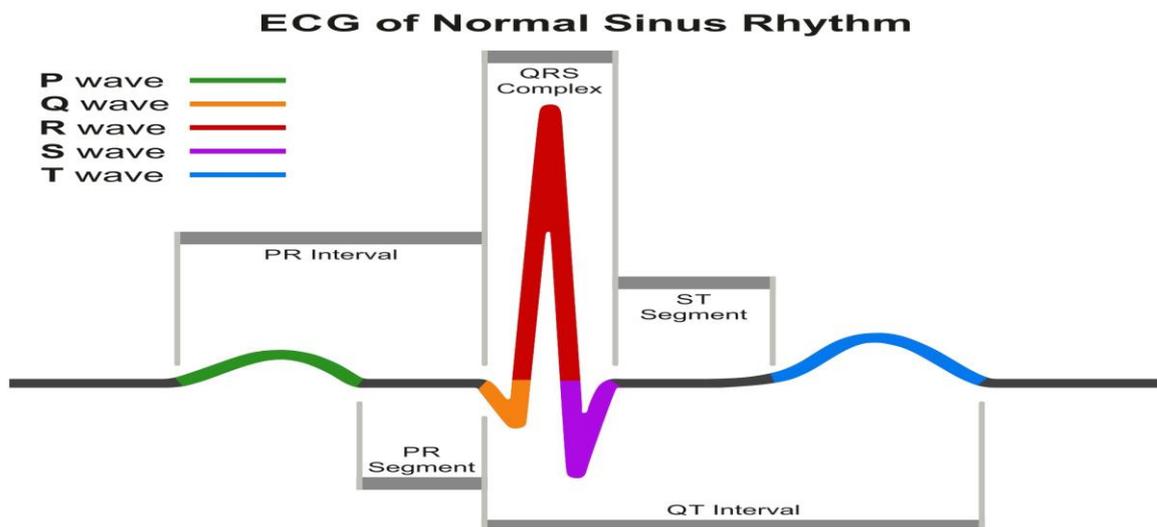
Figure 33 . A normal sinus rhythm on an electrocardiogram (ECG) is a regular heart rhythm originating from the sinoatrial (SA) node, typically showing a consistent rate of 60–100 beats per minute with properly formed P waves before each QRS complex.
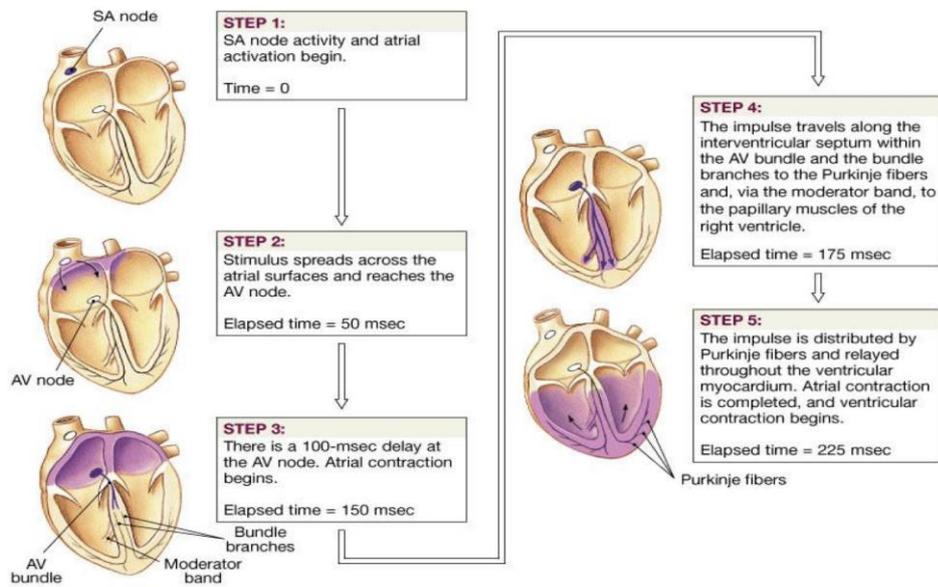
Figure 34 Impulse Conduction through the Heart

D. Components of the Blood and the Lymphatic System:

Blood: A fluid connective tissue composed of:

- Plasma: The liquid medium in which other components are suspended.
- Red blood cells (erythrocytes): Contain hemoglobin, which transports oxygen.
- White blood cells (leukocytes): Function as part of the immune system.
- Platelets (thrombocytes): Cell fragments essential for blood clotting.
- Lymphatic System: An open network of vessels that returns excess fluid and proteins from tissues back to the bloodstream, and plays a vital role in immunity.

Figure 35 Components of Blood

① The clotting process begins when the endothelium of a vessel is damaged, exposing connective tissue in the vessel wall to blood. Platelets adhere to collagen fibers in the connective tissue and release a substance that makes nearby platelets sticky.

② The platelets form a plug that provides immediate protection against blood loss.

③ Unless the break is very small, this plug is reinforced by a fibrin clot.

Collagen fibers

Platelet

Platelet plug

Fibrin clot

Red blood cells caught in threads of fibrin

5 μm

Clotting factors from:
Platelets
Damaged cells
Plasma (factors include calcium, vitamin K)

Enzymatic cascade

Prothrombin → Thrombin

⊕ Positive feedback

Fibrinogen → Fibrin
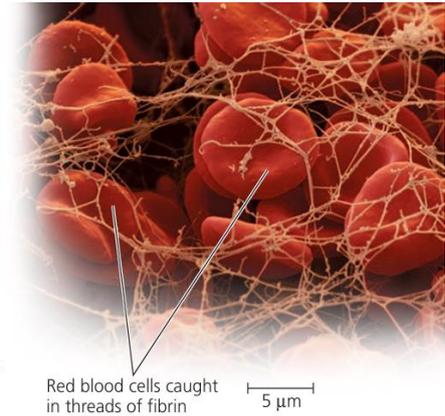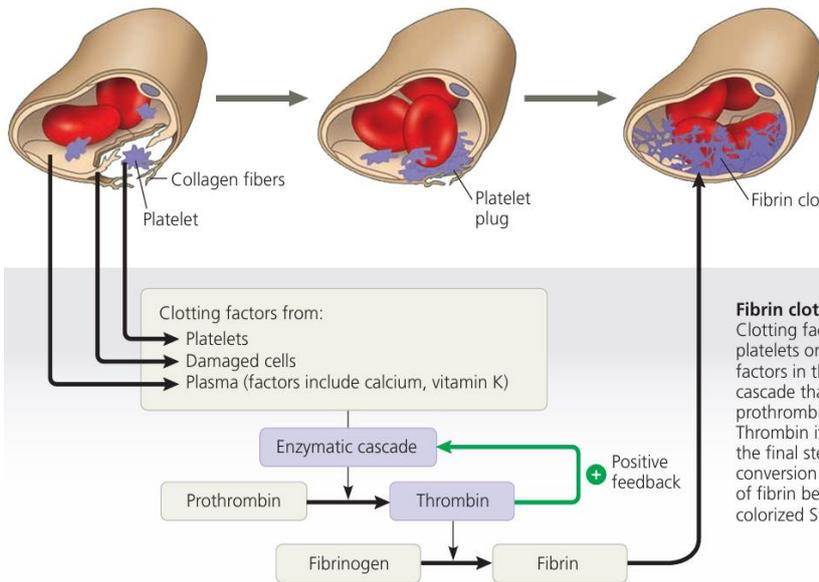
Fibrin clot formation
Clotting factors released from the clumped platelets or damaged cells mix with clotting factors in the plasma, forming an enzymatic cascade that converts a plasma protein called prothrombin to its active form, thrombin. Thrombin itself is an enzyme that catalyzes the final step of the clotting process, the conversion of fibrinogen to fibrin. The threads of fibrin become interwoven into a clot (see colorized SEM above).

Figure 36 Stages of Blood Clotting and Formation of a Thrombus to Stop Bleeding

The Respiratory System: Gas Exchange Network

The respiratory system works in coordination with the circulatory system to supply the body with oxygen and remove carbon dioxide.

A. Principles of Gas Exchange

Gas exchange occurs by diffusion across moist respiratory surfaces. According to Fick's Law, the efficiency of diffusion increases with:

1. An increase in the surface area of the respiratory membrane.
2. A decrease in the diffusion distance.
3. A greater difference in the partial pressure of gases across the surface.

B. Diversity of Respiratory Organs

- Gills: Specialized structures for breathing in water. Fish gills are extremely efficient due to the countercurrent flow mechanism, where blood flows in the opposite direction to water, maximizing oxygen uptake.

- Tracheal System: A network of branched tubes found in insects that delivers air directly to body cells.
- Lungs: Internal sacs adapted for breathing air – a feature that reduces water loss.
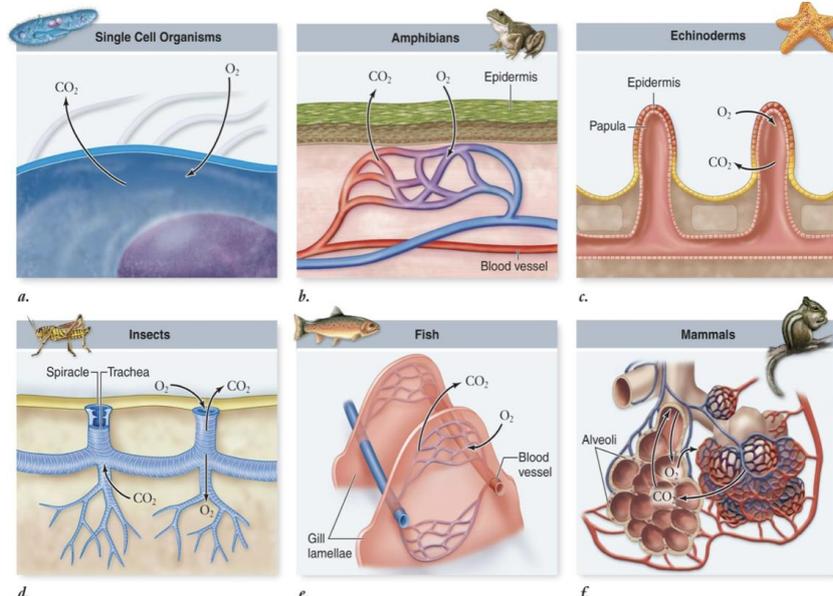
Figure 37 Mechanisms of Gas Exchange in Different Organisms

C. The Respiratory System in Mammals and Birds

- Mammals: The airway consists of the trachea, which branches into bronchi and further into bronchioles, ending in millions of tiny air sacs called alveoli, where gas exchange occurs with the blood. Breathing occurs through a negative pressure mechanism generated by the contraction of the diaphragm and intercostal muscles.
- Birds: Birds possess the most efficient respiratory system among terrestrial vertebrates. Their unidirectional airflow system through the lungs and air sacs prevents the mixing of fresh air with stale air, ensuring continuous oxygen exchange even during exhalation.

D. Gas Transport in the Blood

Blood acts as the transport medium linking the lungs to the body tissues.

- Oxygen Transport: About 98% of oxygen is carried bound to hemoglobin within red blood cells.
- Carbon Dioxide Transport: Carbon dioxide is carried in three forms:

o A small portion dissolved in plasma.

o A portion bound to hemoglobin.

o The majority (about 70%) is converted inside red blood cells into bicarbonate ions ($-HCO_3$), which are then transported in the plasma.

Forced Breathing:

Forced breathing is a type of respiration in which voluntary muscles are used to assist in inhaling or exhaling air from the lungs. It typically occurs when the body requires a greater amount of oxygen or needs to expel carbon dioxide more rapidly, such as during intense exercise or certain medical conditions.

Types of Forced Breathing:

1. Forced Inspiration:

- Involves the use of additional muscles, such as the neck muscles (sternocleidomastoid) and upper back muscles, to expand the chest cavity further.
- Helps bring a larger volume of air into the lungs.

2. Forced Expiration:

- Utilizes the abdominal muscles and internal intercostal muscles to forcefully expel air from the lungs.
- Commonly occurs during coughing, blowing, or intense physical exertion.
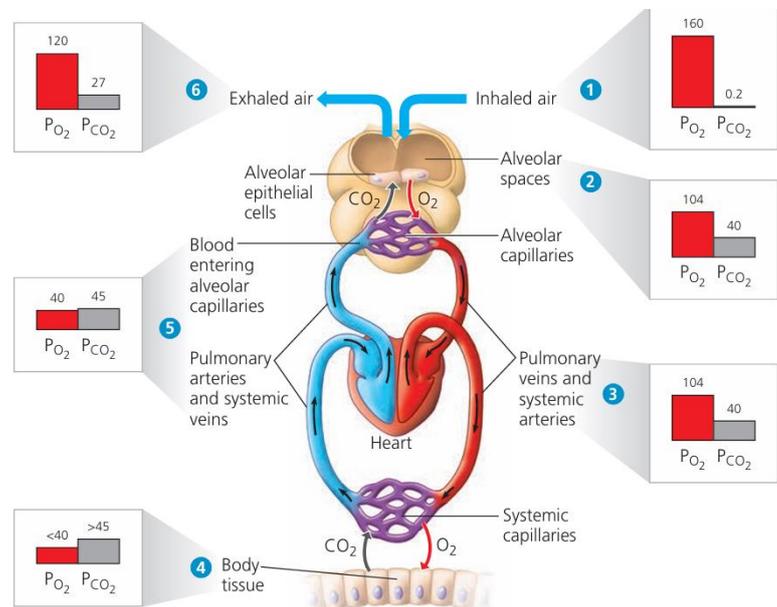
Figure 38 Gas Exchange Between Alveoli and Body Tissues Through the Circulatory System

Chapter Six

The Immune System
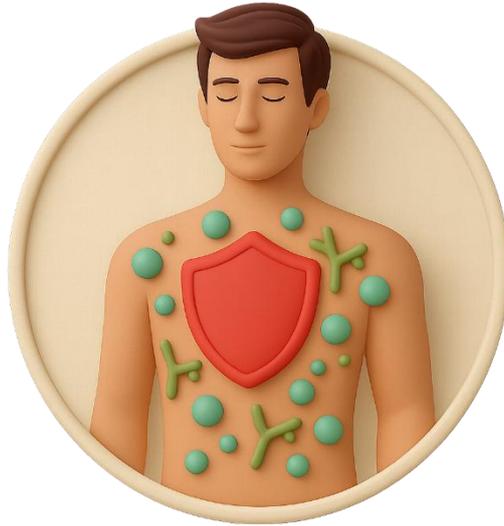
Overview: The Three Lines of Defense

Vertebrates possess a multi-layered defense system to protect the body from pathogens. This system can be divided into three main lines of defense:

1. First Line of Defense (Physical and Chemical Barriers): Represented by the integumentary system (skin and mucous membranes), which prevents the entry of microbes in the first place.

2. Second Line of Defense (Innate/Nonspecific Immunity): A rapid, general response that begins once the first line is breached. It includes specialized cells and proteins that attack any foreign body.

3. Third Line of Defense (Adaptive/Specific Immunity): A highly specialized response that recognizes and eliminates a particular pathogen, characterized by the formation of long-term immune "memory."

The First Line of Defense: Physical and Chemical Barriers

This line serves as a protective shield preventing invaders from entering the body.

- Skin: The largest organ of the body, forming an impermeable physical barrier. It also secretes sweat and oils that make its surface acidic (pH 3–5), inhibiting the growth of many microbes. Sweat contains the enzyme *lysozyme*, which breaks down bacterial cell walls.

- Mucous Membranes: Line the digestive, respiratory, and urogenital tracts. These membranes secrete sticky mucus that traps microbes, which are then expelled or destroyed through various mechanisms:
  - Respiratory system: Cilia move mucus upward to be swallowed and digested in the stomach.
  - Digestive system: Strong stomach acid kills most microbes that reach it.
  - Urogenital system: Acidic secretions and the continuous flow of urine help prevent microbial growth.

The Second Line of Defense: Innate (Nonspecific) Immunity

When the first line is breached, an immediate, non-specific response begins.

A. Innate Immune Cells

1 Pseudopodia surround pathogens.

Pathogen

2 Pathogens are engulfed by endocytosis.

PHAGOCYTIC CELL

3 Vacuole forms, enclosing pathogens.

Vacuole

Lysosome containing enzymes

4 Vacuole and lysosome fuse.

5 Toxic compounds and lysosomal enzymes destroy pathogens.

6 Debris from pathogens is released by exocytosis.
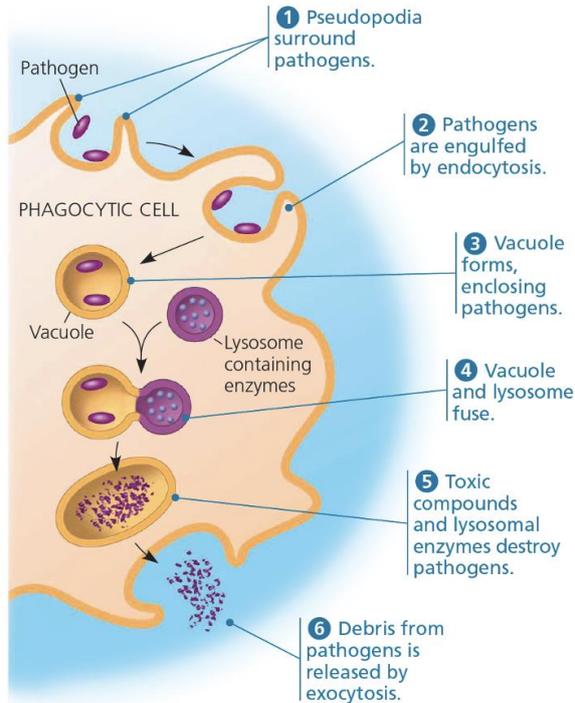
Figure 39 Mechanism of Natural Killer (NK) Cell Action in Immune Defense Against Target Cells

• Macrophages: Large phagocytic cells that roam tissues, engulfing and digesting any foreign particles they encounter - from bacteria and viruses to dead cell debris.

• Neutrophils: The most abundant white blood cells and the first to arrive at the infection site; they efficiently engulf pathogens.

• Natural Killer (NK) Cells: Do not attack microbes directly but specialize in identifying and destroying virus-infected or cancerous body cells by inducing programmed cell death (apoptosis).

B. The Inflammatory Response

It is a localized response to injury or infection, characterized by four main symptoms: redness, heat, swelling, and pain. This response occurs as a result of the release of chemical substances (such as histamine) from damaged cells, causing blood vessels to dilate and become more permeable, allowing immune cells to flow into the affected area.

C. Fever
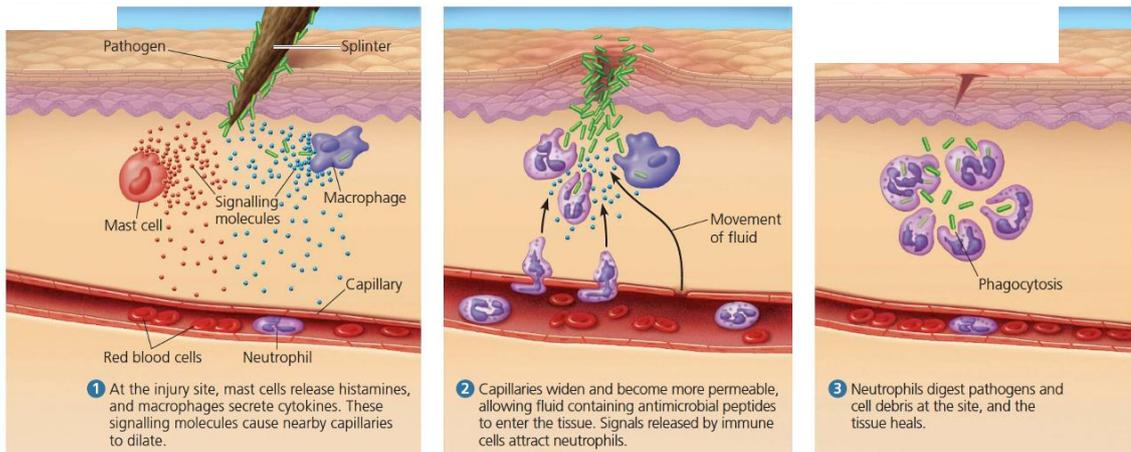
Figure 40 Innate Immune Response Following a Wound and Bacterial Entry

Fever is a systemic (whole-body) response that raises the body's temperature. It is triggered by cytokines (such as interleukin-1) secreted by phagocytic cells and helps inhibit microbial growth while enhancing the activity of immune cells.

D. Antimicrobial Proteins

- Complement System: A group of about 30 proteins found in blood plasma. When activated, they can form pores in microbial membranes (leading to their death) or "tag" them to make phagocytosis easier.
- Interferons: Proteins secreted by virus-infected cells that act as warning signals to neighboring cells, stimulating their antiviral defenses and preventing viral replication.

The Third Line of Defense: Adaptive (Specific) Immunity

This is a highly advanced response characterized by four main features: specificity, diversity, memory, and the ability to distinguish self from non-self.

A. Basics of the Adaptive Response

- Antigen: Any molecule (usually a protein) capable of eliciting a specific immune response.
- Lymphocytes: The key cells of adaptive immunity, divided into two main types:
  o B Cells: Responsible for humoral immunity.
  o T Cells: Responsible for cell-mediated immunity.

This type of immunity targets infected body cells.

- Major Histocompatibility Complex (MHC): Proteins on the surface of body cells that "display" fragments of internal proteins (antigens) to T cells.
- Helper T Cells (CD4): The "commanders" of the immune system. They are activated when they recognize an antigen presented by an antigen-presenting cell (such as a macrophage). Once activated, they secrete cytokines that regulate and activate all other immune cells.
- Cytotoxic T Cells (CD8): The "soldiers." They recognize virus-infected or cancerous body cells displaying foreign antigens on their surfaces and kill them directly.
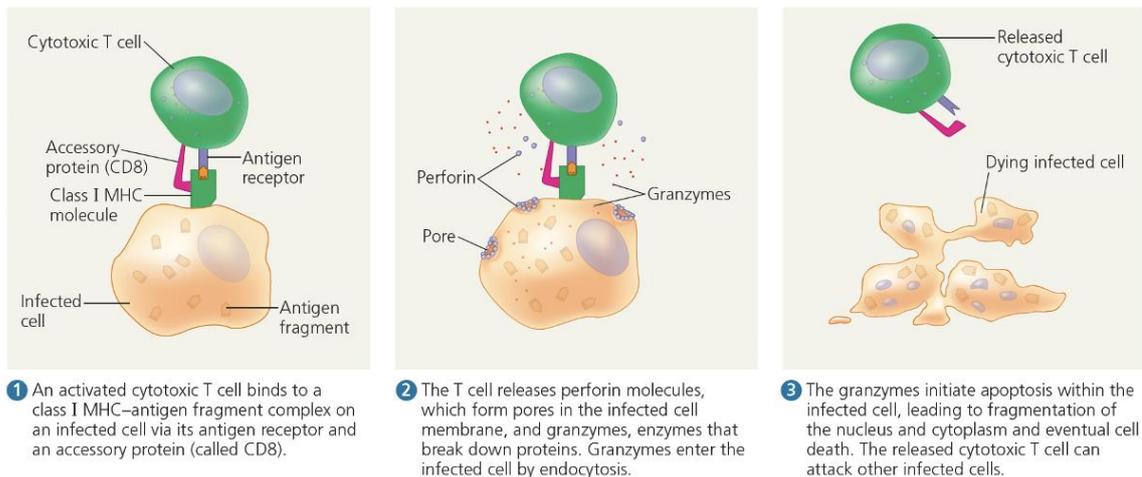
Figure 41 Mechanism of Cytotoxic T (CD8) Cell Action in the Cell-Mediated Immune Response

🖥 **C. Humoral Immunity (Role of B Cells and Antibodies)**

This type of immunity targets pathogens found in body fluids (blood and lymph).

- Activation of B Cells: Occurs when an antigen binds to a B cell receptor, and—along with helper T cell signals—the B cell becomes activated.
- Plasma Cells and Memory Cells: Activated B cells divide into plasma cells (factories that produce antibodies) and long-lived memory cells (the basis of immune memory).
- Antibodies: Y-shaped proteins secreted into body fluids. Antibodies do not kill microbes directly; rather, they neutralize or mark them for elimination by phagocytic cells or the complement system.

Organs of the Immune System

Immune cells develop and become active in specialized lymphoid organs.

- Primary Organs (Sites of Maturation):
  - Bone Marrow: The source of all blood cells and the site where B cells mature.
  - Thymus Gland: The site where T cells mature.
- Secondary Organs (Sites of Activation):
  - Lymph Nodes and Spleen: Act as filters (for lymph and blood, respectively) and are the main locations where lymphocytes encounter antigens to activate the immune response.
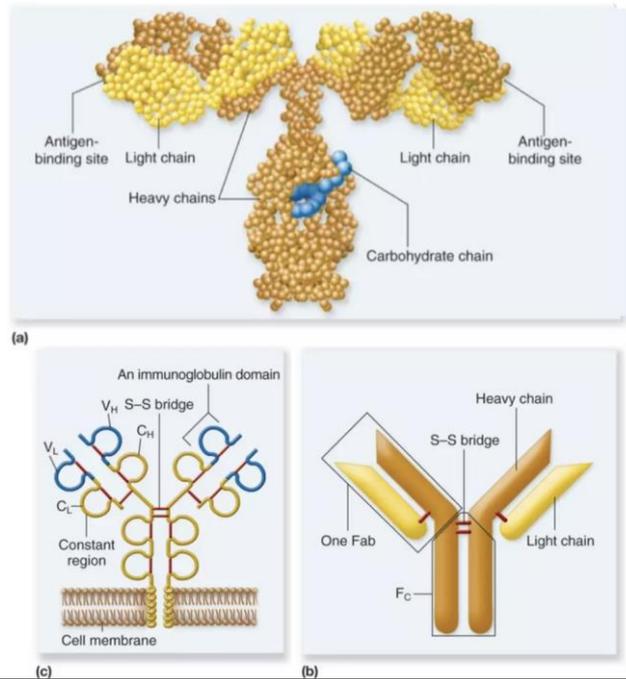
Figure 42 General Structure of Antibodies and Their Key Components

Immune System Applications and Disorders

A. Blood Groups and Organ Rejection

- Blood Groups (ABO and Rh): These are examples of antigens present on the surface of red blood cells. A mismatch during blood transfusion triggers a strong immune response.
- Organ Transplant Rejection: Occurs when the recipient's immune system recognizes the donor organ's MHC proteins as "foreign" and attacks them.

B. Pathogen Evasion Mechanisms

Many microbes have evolved strategies to escape the immune system, such as:

- Antigenic Variation: The influenza virus constantly changes its surface proteins, requiring new vaccines every year.
- Direct Attack on the Immune System: The Human Immunodeficiency Virus (HIV) attacks and destroys helper T cells (CD4), leading to the collapse of the immune system and the development of Acquired Immunodeficiency Syndrome (AIDS).

Chapter Seven

The Excretory System
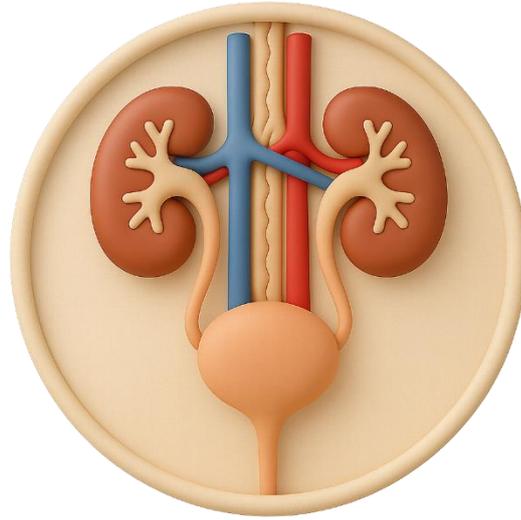
Nitrogenous Wastes: Products of Protein and Nucleic Acid Metabolism

When animals break down amino acids and nucleic acids, they produce nitrogen-containing wastes that must be eliminated. The form in which these wastes are excreted depends on the animal's environment and its need to conserve water.

Forms of Nitrogenous Wastes

1. Ammonia (NH_3): The primary waste product. It is highly toxic and requires large amounts of water to be excreted safely. Therefore, it is the preferred form for most bony fish and aquatic animals, which can release it directly into the water through their gills.

2. Urea: A much less toxic and water-soluble compound. It is synthesized in the liver from ammonia and requires energy to produce, but it allows nitrogen to be excreted with less water loss. This is the main form of nitrogen waste in mammals and adult amphibians.

3. Uric Acid: A very low-toxicity compound with poor solubility in water, allowing it to be excreted as a semi-solid paste with minimal water loss. Its production requires the most energy, but it is a remarkable adaptation for water conservation—essential for animals living in arid environments or those that lay hard-shelled eggs, such as birds, reptiles, and insects.

The Urinary System in Mammals: The Kidney

The kidney is the primary organ responsible for filtering blood, removing metabolic wastes, and regulating the body's water and salt balance.

A. General Structure and Basic Functions

Blood flows into the kidneys through the renal artery, where it is filtered to produce urine. The urine then passes through the ureter to the bladder for temporary storage before being expelled from the body through the urethra. Internally, the kidney consists of an outer cortex and an inner medulla.
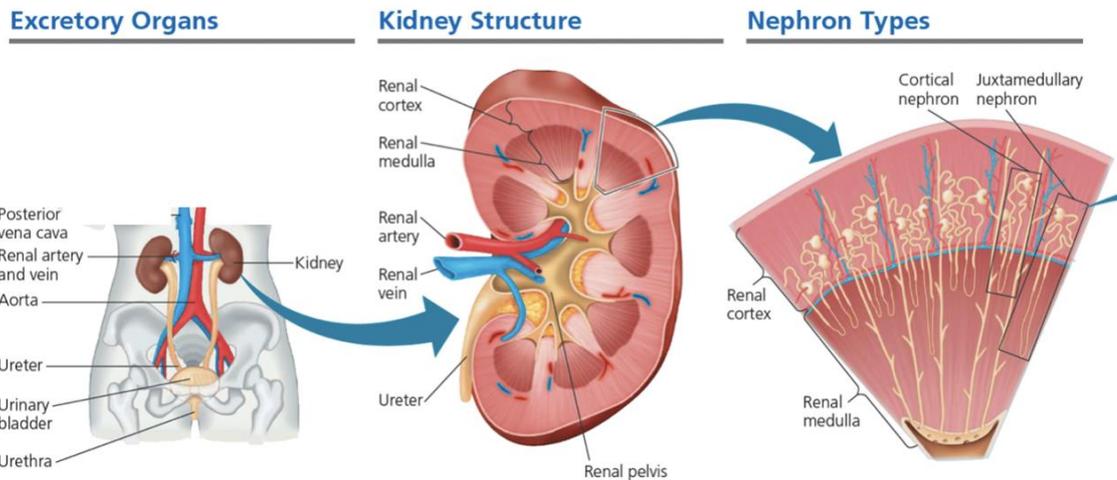
Figure 43 Anatomical Structure of the Urinary System, Kidneys, and the Nephron Unit

The Kidney Performs Three Main Processes:

1. Filtration: Blood plasma is forcefully pushed from the capillaries into the nephron, leaving behind blood cells and large proteins.
2. Reabsorption: Vital substances such as water, glucose, and salts are reabsorbed from the filtrate and returned to the bloodstream.
3. Secretion: Additional wastes, toxins, and excess ions are actively transported from the blood into the filtrate for elimina.

B. The Nephron: The Functional Unit of the Kidney

Each kidney contains about one million microscopic filtering units called nephrons. The nephron is responsible for urine formation through a series of specialized steps.

Main Parts of the Nephron:

- Glomerulus: A network of capillaries where filtration occurs.
- Bowman's Capsule: Surrounds the glomerulus and collects the filtrate.
- Proximal Convoluted Tubule: The site where most water and nutrients are reabsorbed.

- Loop of Henle: A U-shaped structure that plays a crucial role in concentrating urine.
- Distal Convoluted Tubule: Responsible for fine-tuning the balance of salts and water.
- Collecting Duct: Collects urine from multiple nephrons and transports it to the renal pelvis.
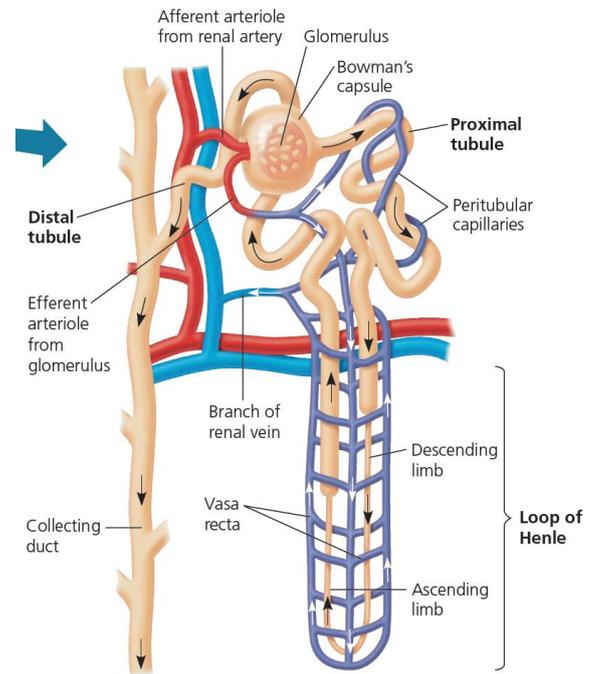
Figure 44 Detailed Structure of the Nephron and the Pathways of Blood and Filtrate Within the Kidney

C. Mechanism of Urine Formation and Concentration (Countercurrent Multiplier System)

The ability of mammals to produce concentrated urine (more concentrated than blood) depends on the structure and function of the Loop of Henle and the collecting duct — a mechanism known as the countercurrent multiplier system.

1. Ascending Limb of the Loop of Henle: Actively pumps out salts (NaCl) into the surrounding kidney medulla but is impermeable to water. This process makes the medullary region highly salty.

2. Descending Limb of the Loop of Henle: Permeable to water but not to salts. As the filtrate moves downward, water leaves the tubule by osmosis into the salty medulla, making the filtrate inside increasingly concentrated.

3. Collecting Duct: Also passes through the highly concentrated medullary region. Under the influence of antidiuretic hormone (ADH), its walls become permeable to water, allowing more water to be reabsorbed into the bloodstream, producing concentrated urine.

Exercises

1	Although connective tissues vary in structure and location, they share a common purpose, connecting and supporting other types of tissues. Although all the following tissues possess this characteristic, one of them is not a connective tissue:
A	Blood
B	Muscles
C	Adipose tissue
D	Cartilage
2	All body organs share the following characteristic:
A	Contain the same types of cells
B	Are composed of several types of cells
C	Are derived from the ectoderm
D	Can be considered part of the circulatory system
3	Epithelial tissues perform all of the following functions except:
A	Forming barriers or boundaries
B	Absorbing nutrients in the digestive system
C	Transmitting information in the central nervous system
D	Allowing gas exchange in the lungs
4	Endocrine and exocrine glands are formed from which type of tissue?
A	Epithelial
B	Connective
C	Nervous
D	Muscular
5	The exoskeleton and endoskeleton differ in the following way:
A	The exoskeleton is rigid, while the endoskeleton is flexible.
B	Endoskeletons are found only in vertebrates.
C	Endoskeletons are found only in vertebrates.
D	Exoskeletons are located outside soft tissues, whereas endoskeletons are located inside the body.
6	Worms and marine invertebrates use a hydrostatic skeleton for movement, in which:

A	Their bones are filled with water that gives the skeleton its weight.
B	Changes in body shape result from muscle contractions that compress body fluids.
C	The muscles contain water-filled cavities that provide a rigid internal structure when filled.
D	The term hydrostatic refers to a moist environment, and movement occurs in a way like arthropods.
7	You have X-ray images of two people: Rabea, a weightlifter and bodybuilder for 30 years, and Basheer, who has spent most of his life sitting. What difference would you expect between their X-ray images?
A	No difference, both have thicker bones than younger people due to natural growth over time.
B	No difference, lifestyle does not affect bone density.
C	Rabea will have thicker bones due to remodeling caused by physical stress.
D	Basheer's bones will be thicker because bone accumulates like fat from sitting.
8	The statement that best describes the sliding filament mechanism of muscle contraction is:
A	The actin and myosin filaments do not shorten, but they slide past each other.
B	The actin and myosin filaments shorten and slide past each other.
C	When the filaments slide past each other, only the actin filaments shorten.
D	When the filaments slide past each other, only the myosin filaments shorten.
9	Simple Nervous System:
A	Must include chemical senses, mechanical senses, and vision
B	Information flows only toward an integration center
C	Information flows away from an integration center
D	Includes sensory input, an integration center, and a response
10	Most neurons in the human brain:
A	Sensory neurons
B	Motor neurons
C	Interneurons
D	Peripheral neurons
11	This type of neuron can extend more than one meter in length:

A	Glial cell in the brain
B	Sensory neurons
C	Interneurons
D	Neurons that control eye movements

12	At the synaptic region, chemical substances (neurotransmitters) are released by:
A	Dendritic membrane
B	Presynaptic membrane
C	Axon
D	Channels on the smooth endoplasmic reticulum

13	In which part of the digestive system is most water reabsorbed?
A	Kidneys
B	Stomach
C	Small intestine
D	Large intestine

14	Why must most food materials be digested?
A	Digestive enzymes require a variety of essential substances
B	To ensure the diet is balanced
C	Most food molecules are too large to be absorbed
D	To prevent intestinal disorders

15	In the digestive system, enzyme A has an optimal pH of 1.5, and enzyme B has an optimal pH of 7. What are the likely substrate types for these enzymes?	
Enzyme	A	B
A	Proteins	Amino acid
B	Fats	Proteins
C	Carbohydrates	Fats
D	Proteins	Fats

16	Which of the following parts of the digestive system secrete protein-digesting enzymes?

	Stomach	Small Intestine	Larg Intestine
A	Yes	Yes	No
B	Yes	No	Yes
C	Yes	No	No
D	No	No	No

17	Which of the following would be an advantage of breathing air rather than water? I. Because air is less dense than water, less energy is required to move it across respiratory surfaces. II. Oxygen diffuses faster in air than in water. III. The oxygen content of air is greater than that of an equal volume of water.
A	Only I and II
B	Only I and III
C	Only II and III
D	I, II and III

18	Which of the following conditions would occur if the lungs lost the elasticity of their alveoli? I. Residual volume decreases. II. The pO_2 of inhaled air must increase in order to maintain hemoglobin saturation at the same level. III. Blood pH increases.
A	Only I
B	Only II
C	Only III
D	I and II
E	I and III
F	II and III

19	Which of the following statements is true regarding gas exchange organs in animals?
A	In a starfish, the gills play a role in gas exchange, but the tube feet do not participate in this process
B	In grasshoppers, the developed muscles surrounding the tracheal tubes control the movement of air in and out through an external opening
C	In fish, blood flows through the filamental capillaries in the same direction as the flow of water from the mouth and pharynx to the outside
D	In birds, during exhalation, the air sacs contract, pushing air outward while the lungs fill with air
E	In humans, a surfactant is required to increase surface tension in the thin fluid layer coating the inner surface of the bronchi; in the absence of surfactant, the alveoli collapse during exhalation, preventing air from entering during inhalation
20	In which of the following structures is the average blood pressure the lowest?
A	Aorta
B	Arteries
C	Arterioles (small arteries)
D	Capillaries
E	Venae cava (superior and inferior vena cava)
21	The systemic inflammatory response that is often life-threatening:
A	Mild fever
B	Dull aches and pain
C	Septic shock
D	High blood pressure
22	Both the eyes and the respiratory system are protected against infections by:
A	The mucous membranes covering their surfaces
B	The secretion of complement proteins
C	The release of slightly alkaline secretions
D	The secretion of lysozyme on their surfaces

23	Antihistamine treatment reduces:
A	Vasodilation
B	Phagocytosis of antigens
C	MHC presentation by macrophages
D	Secondary immune response
24	The cells and signaling molecules that initiate inflammatory responses:
A	Phagocytes and lysosomes
B	Phagocytes and chemicals
C	Stem cells and interferon
D	Mast cells and histamine
25	A bacterial infection in a previously uninfected house cat would most rapidly activate:
A	Toll-like receptors (TLRs) that bind to lipopolysaccharides
B	Memory cells to produce antibodies
C	Plasma cells to produce antigens
D	Exhaustion of all innate immune response options
26	A key part of the humoral immune response is:
A	The attack of cytotoxic T cells on infected host cells
B	The production of antibodies by plasma cells
C	The perforation of infected host cells by perforin
D	The phagocytic attack on living pathogens
27	One of the main functions of the excretory system is to eliminate excess nitrogen produced by metabolism. Which of the following organisms is most efficient at packaging or processing nitrogen for excretion?
A	Frog
B	Freshwater fish
C	Iguana
D	Camel
28	The blood of sharks is isotonic with seawater because of the reabsorption of:
A	Ammonia

B	Uric acid
C	Urea
D	Sodium chloride
29	Functions of the kidney:
A	Removing harmful substances from the body
B	Reabsorbing water for reuse
C	Regulating the level of salts in the blood
D	All the above
30	If an infection affects the process of ion reabsorption from the filtrate, it would damage cells located in:
A	Bowman's capsule
B	renal tubules
C	Glomerulus
D	Collecting duct

1- A person is sick from the COVID-19 virus. What kind of immunity does this person gain due to the infection and then retain after recovery?

A. Active immunity, innate immunity

B. Active immunity, acquired immunity

C. Passive immunity, innate immunity

 D. Passive immunity, acquired immun.

2. The figure below shows the biceps brachii, which is a muscle that flexes the lower arm . The arrows indicate the tension force acting on the lower arm bone. Consider the following statements:

I. Biceps brachii can be voluntarily controlled.

II. The muscle cell of the biceps brachii must have a striated appearance with multiple nuclei.

III. The neurotransmitter released by the motor neurons involved in contraction of biceps brachii is glutamate.

(Modified from Betts et al., 2022)
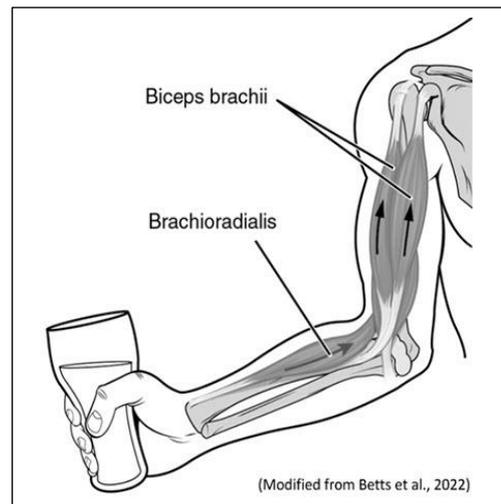
Which statement(s) (I–III) is/are correct?

A. I only

B. II only

C. I and II

D. I and III

3- The diagram shows blood circulation in a fish. (1: gill circulation, 2: gill capillaries, 3: body capillaries, 4: systemic circulation)

(Modified from Betts et al., 2022)
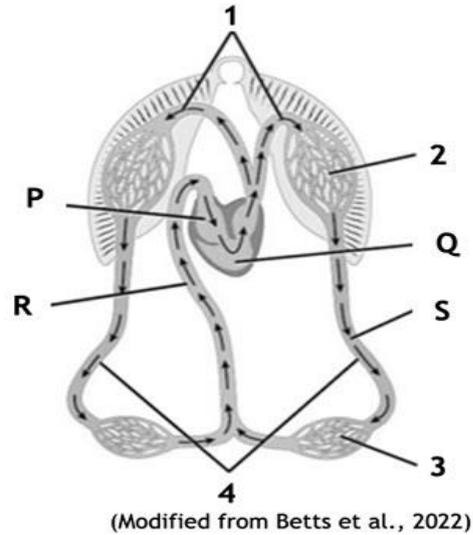
Which of the following statements are correct?

I. P is a ventricle of the heart.

II. Blood in Q is oxygenated.

III. R is a vein.

IV. Blood pressure in S is higher than in R.

A. I and II

B. I and IV

C. II and III

D. III and IV

Answer Keys for Exercises and the Mock Exam

Exercises

B	18	B	1
D	19	B	2
E	20	C	3
C	21	A	4
D	22	D	5
A	23	B	6
D	24	C	7
A	25	A	8
B	26	D	9
D	27	C	10
C	28	B	11
D	29	B	12
B	30	C	13
		C	14
		D	15
		C	16
		A	17

Mock Exam

Answers	Questions
B	1
C	2
D	3

Part Two

Botany

Introduction to Botany:

Botany is one of the major branches of the biological sciences and is concerned with the study of plants in terms of their structure, functions, genetics, environment, and evolution. Plants constitute the primary producers in most terrestrial and marine ecosystems, as they convert solar energy into chemical energy through photosynthesis. This process provides the organic compounds and oxygen essential for the survival of most forms of life on Earth. Modern botany is not limited to describing or morphologically classifying plants; rather, it integrates molecular biology, biochemistry, genomics, and ecology to understand the mechanisms that regulate growth, development, and adaptation. At the cellular level, botanists study processes such as cell wall synthesis, plant hormone signaling, and metabolic pathways related to growth and responses to environmental stresses. On a broader scale, botany examines plant diversity, evolutionary relationships among species, and the ecological interactions that determine species distribution and success. The importance of these studies continues to grow considering rapid climate change, habitat loss, and the increasing global demand for food.

Objectives

1. To understand the hierarchical organization of plants, including the structure and function of organs, tissues, and cells.

2. To identify the different types of meristems and explain how each contributes to primary and secondary growth.

3. To describe the mechanisms and outcomes of primary growth, focusing on how it extends the length of roots and shoots.

4. To analyze the process of secondary growth and its role in increasing the thickness of stems and roots in woody plants.

5. To explain how growth, morphogenesis, and cell differentiation interact to form the complete plant body.

6. To relate meristem activity to overall plant form and developmental patterns.

7. To compare primary vs. secondary tissues and understand how each supports plant structure and function.

Chapter 1

The structure, growth, and formation of vascular plants
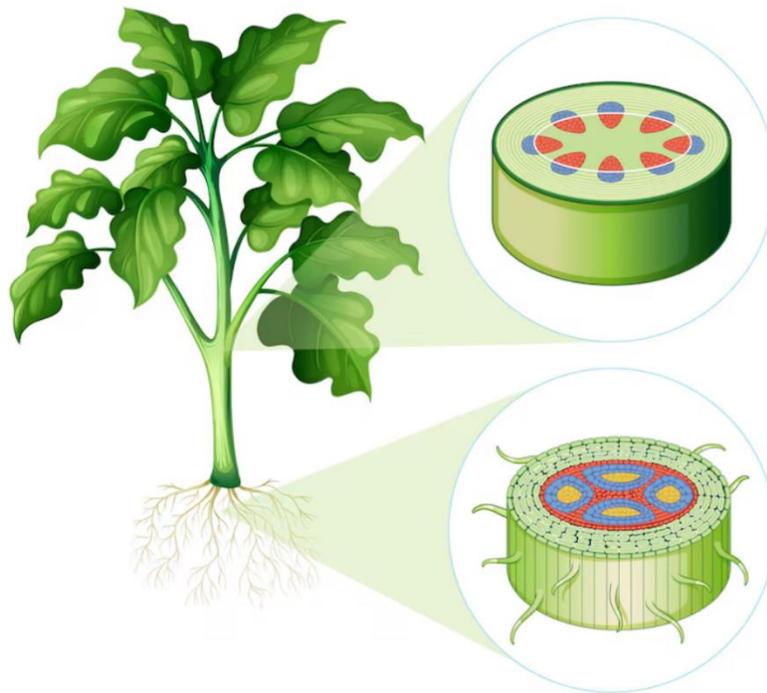
Plants have a hierarchical organization consisting of organs, tissues, and cells:

- Plants, like most animals, are composed of cells, tissues, and organs.
- As you learn about each level of plant organization, keep in mind how natural selection has produced plant forms suited to their functions at all levels of organization.

Basic Vascular Plant Organs: Roots, Stems, and Leaves:

The basic form of vascular plants reflects their evolutionary history as organisms that live on land (terrestrial). These organs form a root system and a shoot system, the latter consisting of stems and leaves (see figure). Vascular plants depend on both systems for survival

Roots:

A root is the organ that anchors a vascular plant in the soil, absorbs minerals and water, and often stores carbohydrates and other reserves.

The primary root, which originates in the seed embryo, is the first organ to emerge from a germinating seed. It soon branches to form lateral roots (as shown in the figure).

Tall, erect plants with large shoot masses generally have a taproot system, consisting of one main vertical root, the taproot, which typically develops from the primary root.

Figure 45 **An overview of a flowering plant**

Small vascular plants are particularly vulnerable to grazing animals that can uproot and kill them. Such plants are more securely anchored by a fibrous root system, a dense mat of thin roots spreading just below the soil surface.

Most root systems also form mycorrhizal associations, symbiotic interactions with soil fungi that enhance the plant's ability to absorb minerals.

The roots of many plants are adapted to perform specialized functions (see figure).

Most root systems also form mycorrhizal associations, which are symbiotic interactions with soil fungi that enhance the plant's ability to absorb minerals.

The roots of many plants are also adapted to perform specialized functions.

Figure 46 Prop roots

Figure 47 Pneumatophores

Figure 48 Storage roots

Figure 49 Buttress roots

Figure 50 Root hairs

Stems

A stem is a plant organ that bears leaves and buds. Its main function is to elongate and orient the shoot in a way that maximizes photosynthesis by the leaves. Another function of stems is to elevate reproductive structures, thereby facilitating the dispersal of pollen and fruit. Green stems may also carry out a limited amount of photosynthesis. Some plant stems perform alternative functions, such as food storage or asexual reproduction. Many of these modified stems are often mistaken for roots, including rhizomes, tubers, and stolons

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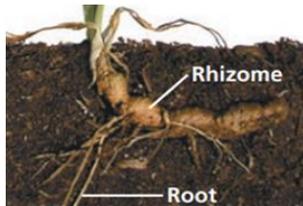
Figure 51 modified stems

Leaves

In most vascular plants, the leaf is the main organ of photosynthesis. In addition to intercepting light, leaves exchange gases with the atmosphere, dissipate heat, and defend themselves from herbivores and pathogens. These functions may sometimes have conflicted physiological, anatomical, or morphological requirements. For example:

A dense covering of hairs may help deter herbivorous insects but can also trap air near the leaf surface, reducing gas exchange and thus photosynthesis. In general, a leaf consists of a flattened blade and a stalk, the petiole, which attaches the leaf to the stem at a node.

Monocots and eudicots differ in the arrangement of veins (the leaf's vascular tissues).

Almost all leaves are specialized for photosynthesis; however, some species have leaves with adaptations that enable them to perform additional functions, such as support, protection, storage, or reproduction.

Figure 52 adaptations of leaves

Simple leaf

A simple leaf has a single, undivided blade. Some simple leaves are deeply lobed, as shown here.

Axillary bud — Petiole

Compound leaf

In a compound leaf, the blade consists of multiple leaflets. A leaflet has no axillary bud at its base. In some plants, each leaflet is further divided into smaller leaflets.

Leaflet

Axillary bud — Petiole
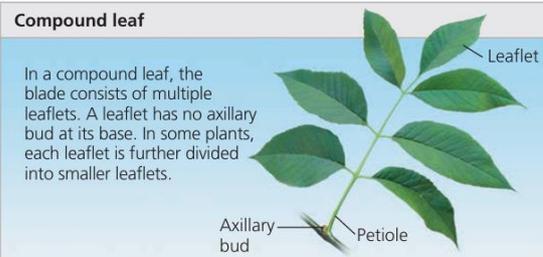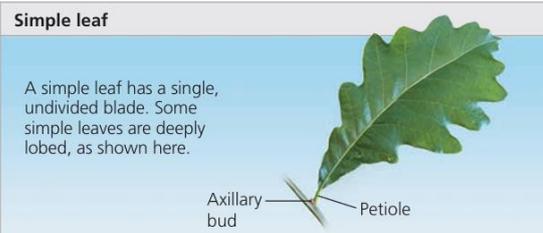
Figure 53 Simple versus compound leaves

Dermal, Vascular, and Ground Tissues

All three basic organs of vascular plants — roots, stems, and leaves — are composed of three fundamental tissue types: dermal tissue, vascular tissue, and ground tissue.

Each of these general types forms a continuous tissue system throughout the plant, connecting all organs. The arrangement and location of these tissues vary from one organ to another.

The three tissue systems

Dermal Tissue	Vascular Tissue	Ground Tissue
The dermal tissue system provides a protective cover for the entire body of a plant.	The vascular tissue system, which transports materials between the root and shoot systems	The ground tissue system, which is responsible for most of the metabolic functions, is located between the dermal tissue and the vascular tissue in each organ
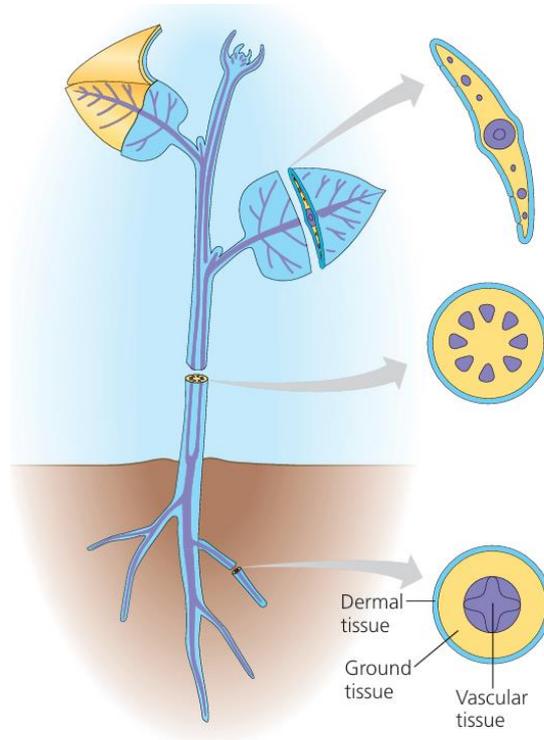
Figure 54. The three tissue systems in plants

◻ Common Types of Plant Cells

Parenchyma Cells
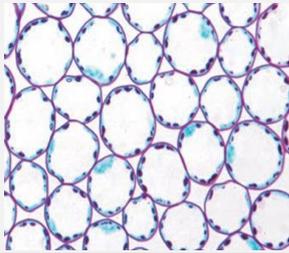
Figure 55. Parenchyma cells

Mature parenchyma cells have primary walls that are relatively thin and flexible, and most lack secondary walls. When mature, parenchyma cells generally have a large central vacuole. Parenchyma cells perform most of the metabolic functions of the plant, synthesizing and storing various organic products. For example, photosynthesis occurs within the chloroplasts of parenchyma cells in the leaf. Some parenchyma cells in stems and roots have colorless plastids that store starch. Most parenchyma cells retain the ability to divide and differentiate into other types of plant cells

Collenchyma Cells
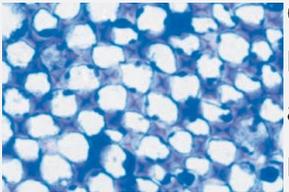
Figure 56. Collenchyma cells

Grouped in strands, collenchyma cells (seen here in cross section) help support young parts of the plant shoot. Collenchyma cells are generally elongated cells that have thicker primary walls than parenchyma cells, though the walls are unevenly thickened. Young stems and petioles often have strands of collenchyma cells just below their epidermis. Collenchyma cells provide flexible support without restraining growth. At maturity, these cells are living and flexible, elongating with the stems and leaves they support

Sclerenchyma Cells
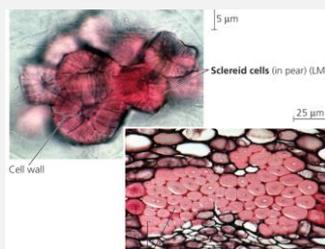
Figure 57. Sclerenchyma cells

Sclerenchyma cells also function as supporting elements in the plant but are much more rigid than collenchyma cells. In sclerenchyma cells, the secondary cell wall is thick and contains large amounts of lignin a relatively indigestible strengthening polymer that occur in regions of the plant that have stopped growing in length. Sclerenchyma cells are so specialized for support that many are dead at functional maturity. There are Two types of sclerenchyma cells, known as sclereids and fibers. Sclereids impart the hardness to nutshells and seed coats, Fibers, which are usually grouped in strands, are long, slender, and tapered. Some are used commercially, such as hemp fibers for making rope and flax fibers for weaving into linen.

Water-Conducting Cells of the Xylem
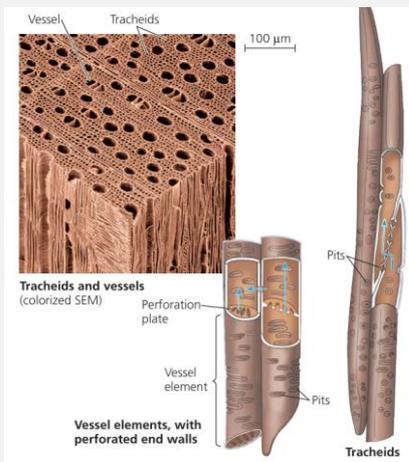
Figure 58. Cells of the Xylem

There are two types of water-conducting cells: tracheids and vessel elements. These are elongated, tubular, dead, and lignified cells at functional maturity.

Tracheid's occur in all vascular plants, whereas in most angiosperms and some gymnosperms, vessel elements are present in addition to tracheids.

Tracheids and vessel elements form non-living channels through which water flows. The secondary walls of tracheids and vessel elements often intersect through pits, which are thin regions that allow water to move laterally. The secondary walls of tracheids and vessel elements are reinforced with lignin, which provides structural support and protects them from collapsing under the tension generated during water transport.

Sugar-Conducting Cells of the Phloem
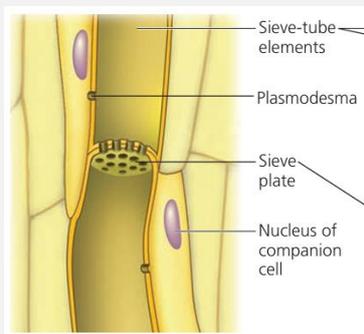
Figure 59. Cells of the Phloem

Phloem cells transport sugars and other nutrients through long, narrow cells called sieve tubes, which are composed of chains of cells known as sieve-tube elements. Although sieve-tube elements are living cells, they lack a nucleus, ribosomes, and a large central vacuole. This reduction in cellular contents allows nutrients to pass through more easily. The end walls between sieve-tube elements, known as sieve plates, contain pores that facilitate the flow of sap from one cell to the next. Adjacent to each sieve-tube element are non-conducting cells called companion cells, which assist in loading sugars into the sieve tube.

Different meristems generate new cells for primary and secondary growth

The main difference between plants and most animals is that plant growth is not limited to the embryonic period. Instead, growth occurs throughout the plant's lifetime, a process known as indeterminate growth. Plants can continue to grow because they possess undifferentiated tissues called meristems, which contain cells capable of division, producing new cells that elongate and become differentiated. There are two main types of meristems: apical meristems (located at the tips of roots and shoots) and lateral meristems (responsible for thickening growth). Primary growth allows roots to extend throughout the soil and shoots to grow upward, increasing their exposure to light.
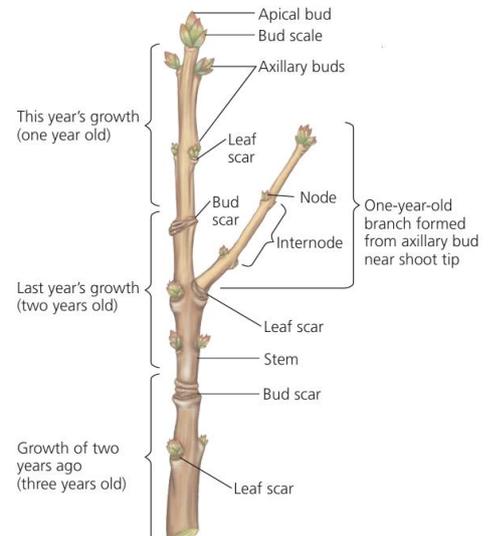
Figure 60. Three years' growth in a winter twig

Figure 61. Visualizing Primary Growth in plant
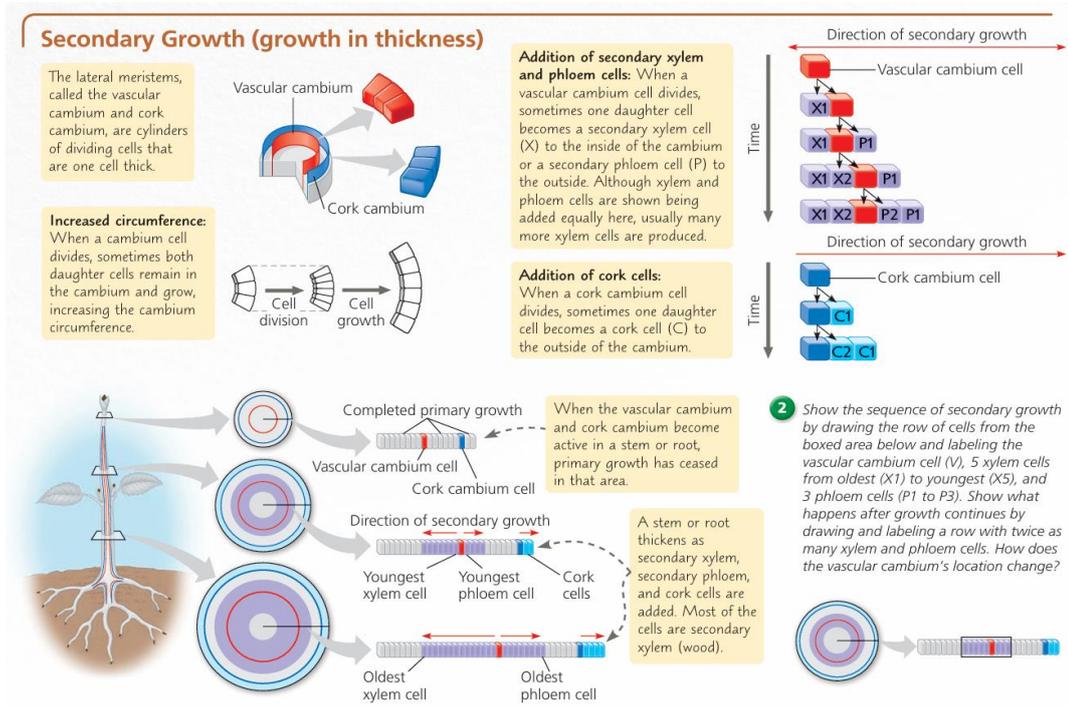
Figure 62. Visualizing secondary Growth in plant

▣ Primary growth lengthens roots and shoots

▣ Primary Growth of roots

The entire biomass of a primary root is derived from the root apical meristem. The root apical meristem also makes a thimble-like root cap, which protects the delicate apical meristem as the root pushes through the abrasive soil. Growth occurs just behind the tip in three overlapping zones of cells at successive stages of primary growth. These are:

- The zones of cell division
- The zone of elongation
- The zone of differentiation

▣ Root Growth and Anatomy

- Root hairs are the most prominent feature of the root epidermis.
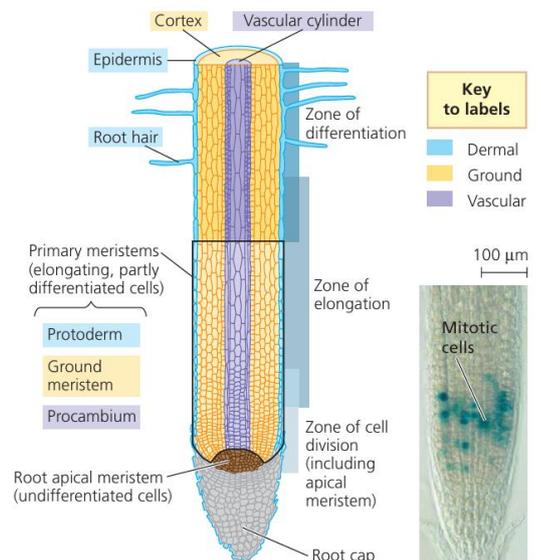
Figure 63. primary growth of a eudicot root

- The cortex is the region between the vascular tissues and the epidermis, and it is composed mainly of parenchyma cells.
- The endodermis acts as a selective barrier that regulates the passage of substances from the soil into the vascular cylinder.
- The procambium gives rise to the vascular cylinder, which consists of a solid core of xylem and phloem tissues surrounded by a single layer of cells called the pericycle. Lateral (branch) roots originate from the meristematic regions of the pericycle, which is the outermost cell layer of the vascular cylinder, located just inside and adjacent to the endodermis, The emerging lateral roots grow destructively through the outer tissues until they emerge from the established root.
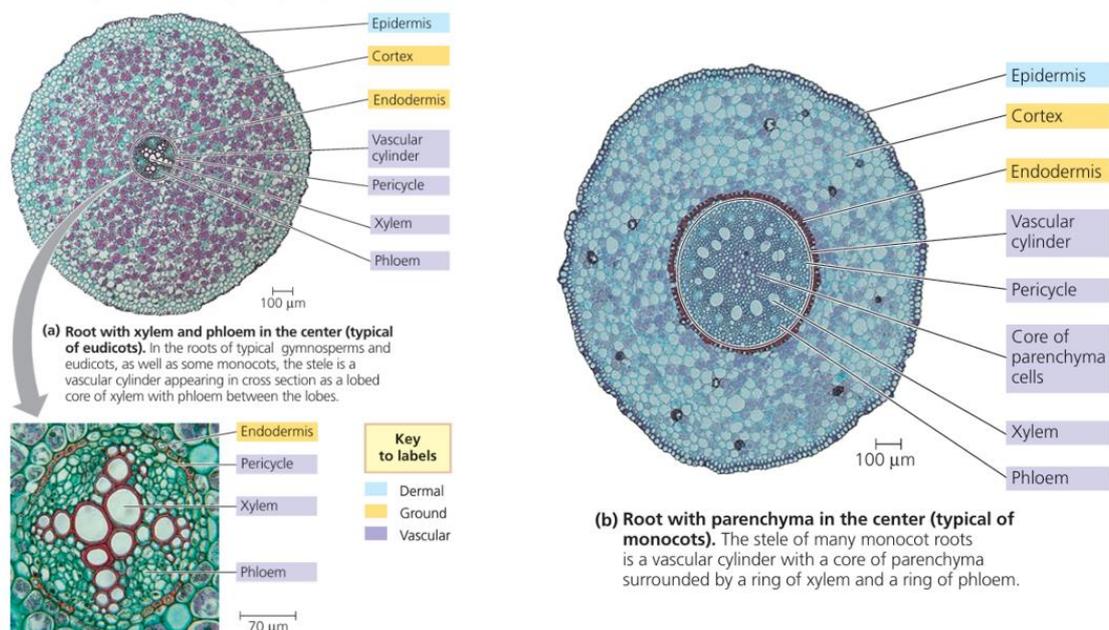
Figure 64. The internal structure of the root in monocots and dicots7

Primary Growth of Shoots:

The entire primary shoot biomass—including all its leaves and stems—is derived from the shoot apical meristem, a dome-shaped mass of dividing cells located at the tip of the stem (see figure). Branching of shoots, which is also part of primary growth, arises from the activation of axillary buds, each of which contains its own apical meristem. Due to chemical signaling through plant hormones, the closer an axillary bud is to an active apical bud, the more it is inhibited—a phenomenon known as apical dominance.

The shoot tip. Leaf primordia arise from the flanks of the dome of the apical meristem. This is a longitudinal section of the shoot tip of *Coleus* (LM).

- Leaf primordia
- Young leaf
- Shoot apical meristem
- Protoderm
- Procambium
- Ground meristem
- Axillary bud meristems

0.25 mm
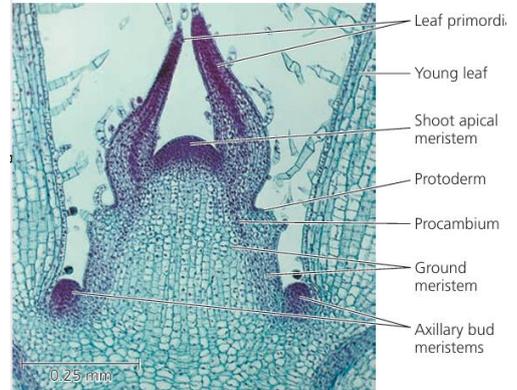
Figure 65. A longitudinal section of the shoot tip

Stem Growth and Anatomy

The stem is covered by an epidermis, usually one cell layer thick, and coated with a waxy cuticle that prevents water loss. Examples of specialized epidermal cells in the stem include protective cells and trichomes (glandular hairs or outgrowths found on the stems and leaves of many plants). The ground tissue of stems consists mainly of parenchyma cells. Collenchyma cells, located just beneath the epidermis, provide support for many stems during primary growth. Sclerenchyma cells, particularly fiber cells, also contribute to support in regions of the stem that are no longer elongating. The vascular tissues extend along the stem in distinct vascular bundles.
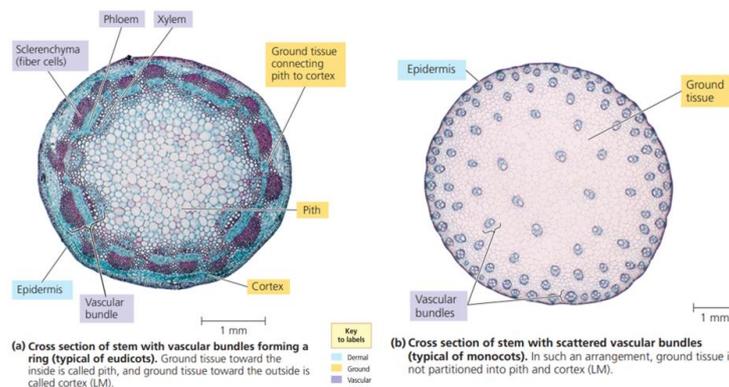
Figure 66. The stem structure in monocots and dicots

Leaf Growth and Anatomy

- The epidermis of a leaf is covered by a waxy cuticle, except in areas where stomata are present. These stomata allow the exchange of carbon dioxide (CO_2) and oxygen (O_2) between the surrounding air and the photosynthetic cells inside the leaf. In addition to regulating the uptake of carbon dioxide for photosynthesis, the stomata are also the primary pathways for water vapor loss (transpiration). And they surrounded by two specialized epidermal cells known as guard cells.

- The ground tissue of the leaf, called the mesophyll (literally "middle leaf"), is located between the upper and lower epidermal layers. And differentiated into two distinct layers:

  ○ The palisade mesophyll consists of one or more layers of elongated parenchyma cells located in the upper part of the leaf.

  ○ The spongy mesophyll lies beneath the palisade layer and is made up of loosely arranged parenchyma cells with intercellular air spaces through which CO_2 and O_2 circulate around the cells and up to the palisade region.

- The vascular tissues of each leaf are connected to those of the stem.

- The veins branch repeatedly and spread throughout the mesophyll, forming a network that brings the xylem and phloem into close contact with the photosynthetic tissue. Through this network, the xylem supplies water and minerals, while the phloem transports sugars and other organic products to other parts of the plant.
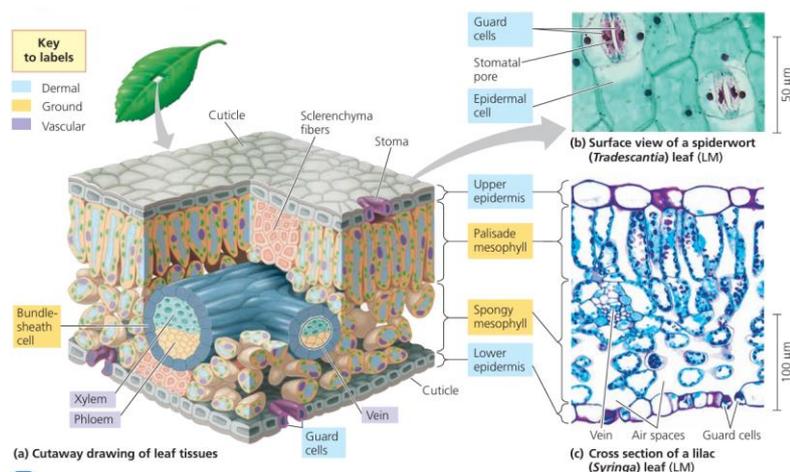
Figure 67. Leaf anatomy

Secondary growth increases the diameter of stems and roots in woody plants

All gymnosperms and many eudicot species undergo secondary growth, but it is uncommon in monocots. This type of growth occurs in the stems and roots of woody plants, but only rarely in leaves. Secondary growth consists of tissues produced by the vascular cambium and the cork cambium.

Primary and secondary growth of a woody stem.

Epidermis
Cortex
Primary phloem
Vascular cambium
Primary xylem
Pith

Periderm (mainly cork cambia and cork)
Primary phloem
Secondary phloem
Vascular cambium
Secondary xylem
Primary xylem
Pith

Pith
Primary xylem
Vascular cambium
Primary phloem
Epidermis
Cortex

Growth
③ Vascular ray
Primary xylem
Secondary xylem
Vascular cambium
Secondary phloem
Primary phloem
First cork cambium
Cork

Growth
Secondary xylem (two years of production)
Vascular cambium
Secondary phloem
⑦ Most recent cork cambium
Cork
⑨ Bark
⑧ Layers of periderm

① Primary growth from the activity of the apical meristem is nearing completion. The vascular cambium has just formed.

② Although primary growth continues in the apical bud, only secondary growth occurs in this region. The stem thickens as the vascular cambium forms secondary xylem to the inside and secondary phloem to the outside.

③ Some stem cells of the vascular cambium give rise to vascular rays

④ As the vascular cambium's diameter increases, the secondary phloem and other tissues external to the cambium can't keep pace because their cells no longer divide. As a result, these tissues, including the epidermis, will eventually rupture. A second lateral meristem, the cork cambium, develops from parenchyma cells in the cortex. The cork cambium produces cork cells, which replace the epidermis.

⑤ In year 2 of secondary growth, the vascular cambium produces more secondary xylem and phloem. Most of the thickening is from secondary xylem. Meanwhile, the cork cambium produces more cork.

⑥ As the stem's diameter increases, the outermost tissues exterior to the cork cambium rupture and are sloughed off.

⑦ In many cases, the cork cambium re-forms deeper in the cortex. When none of the cortex is left, the cambium develops from phloem parenchyma cells.

⑧ Each cork cambium and the tissues it produces form a layer of periderm.

⑨ Bark consists of all tissues exterior to the vascular cambium.

Figure 68. primary and secondary growth of a woody stem.

Genetic Control of Flowering:

Flower formation involves a phase change from vegetative growth to reproductive growth. This transformation is triggered by a combination of environmental signals, such as day length, and internal signals, such as hormones. The transition from vegetative growth to flowering is associated with the switching on of floral meristem identity genes. The protein products of these genes are transcription factors that regulate other genes required to transform indeterminate vegetative meristems into determinate floral meristems.

These floral organs are arranged in four concentric whorls, which can be described as roughly circular layers when viewed from above.
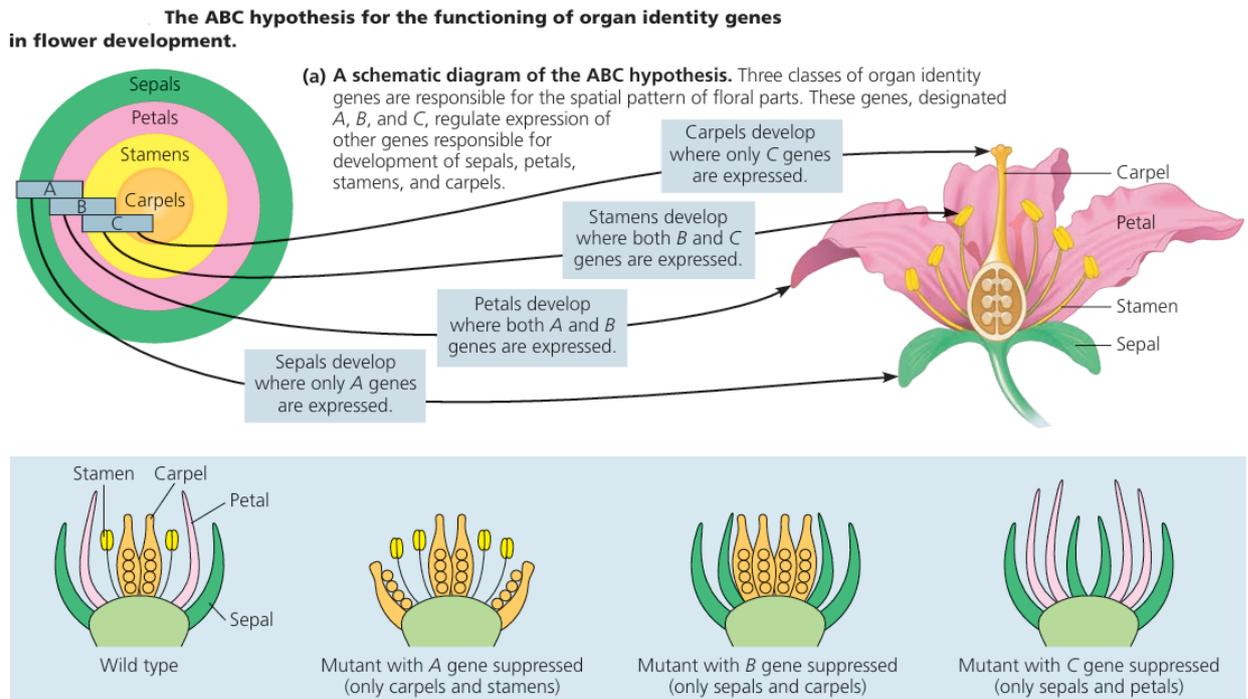
Figure 69. The ABC hypothesis for the functioning of organ identity genes in flower development.

Chapter Two

Acquisition and Transport of Resources in Vascular Plants

Adaptations for acquiring resources were key steps in the evolution of vascular plants:

Most plants grow in soil and therefore live in two worlds: above ground, where the shoot system acquires sunlight and carbon dioxide (CO_2), and below ground, where the roots absorb water and minerals. The following figure provides an overview of resource acquisition and transport in an actively photosynthesizing plant
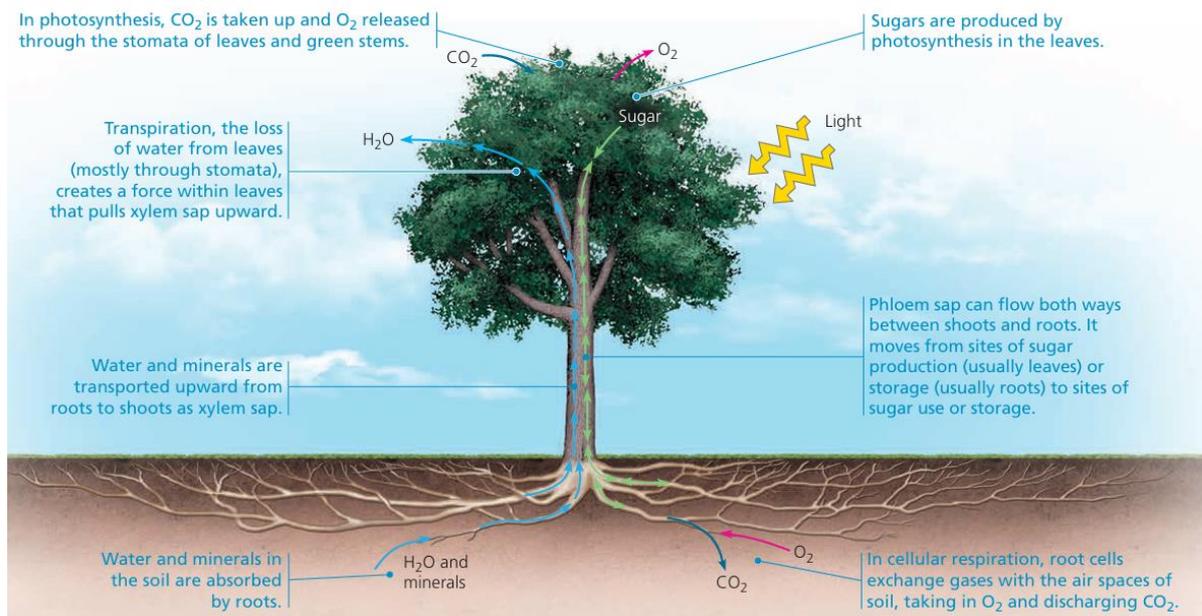
figure 70. An overview of resource acquisition and transport in a vascular plant

Adaptations of roots and leaves for resource acquisition

Root Architecture and Acquisition of Water and Minerals:	Shoot Architecture and Light Capture
1. Modification in root structure and composition. 2. Beneficial relationships with microorganisms	1. Variation in branching patterns 2. Diversity in leaf size and structure 3. Leaf arrangement on the stem

 Different mechanisms transport substances over short or long distances:

 Short-Distance transport of Water across Plasma membranes

Absorption or loss of water by a cell occurs through osmosis, the diffusion of free water—that is, water not bound to solutes or surfaces—across a membrane.

The physical property that predicts the direction of water movement is called water potential (Ψ). It is a quantity that combines the effects of solute concentration and physical pressure.

Free water moves from regions of higher water potential (higher Ψ) to regions of lower water potential (lower Ψ), provided there is no barrier to its flow.

Water potential is abbreviated by the Greek letter Ψ (psi). Plant biologists measure Ψ in a pressure unit called the megapascal (MPa).

By definition, the Ψ of pure water in an open container exposed to the atmosphere under standard conditions (at sea level and room temperature) is 0 MPa.

Let us now consider how water potential (Ψ) affects the absorption and loss of water by a living plant cell.

First, imagine a flaccid (limp) cell that has lost water. In this case, the cell's pressure potential (ΨP) is 0 MPa. Suppose this flaccid cell is immersed in a solution with a higher solute concentration than that inside the cell (Figure a).

Because the external solution has a lower (more negative) water potential, water diffuses out of the cell, and the protoplast of the cell undergoes plasmolysis—that is, it shrinks and pulls away from the cell wall.

If the same flaccid cell is placed in pure water (Ψ = 0 MPa) (Figure b), the cell, which contains solutes, has a lower water potential than pure water. As a result, water enters the cell by osmosis. The contents of the cell begin to swell, pressing the plasma membrane against the cell wall. The partially elastic wall exerts a turgor pressure (ΨP) that confines the swollen protoplast. When this turgor pressure is sufficient to balance the tendency of water to enter because of the solutes in the cell, then ΨP and ΨS are equal in magnitude but opposite in sign, making Ψ = 0.
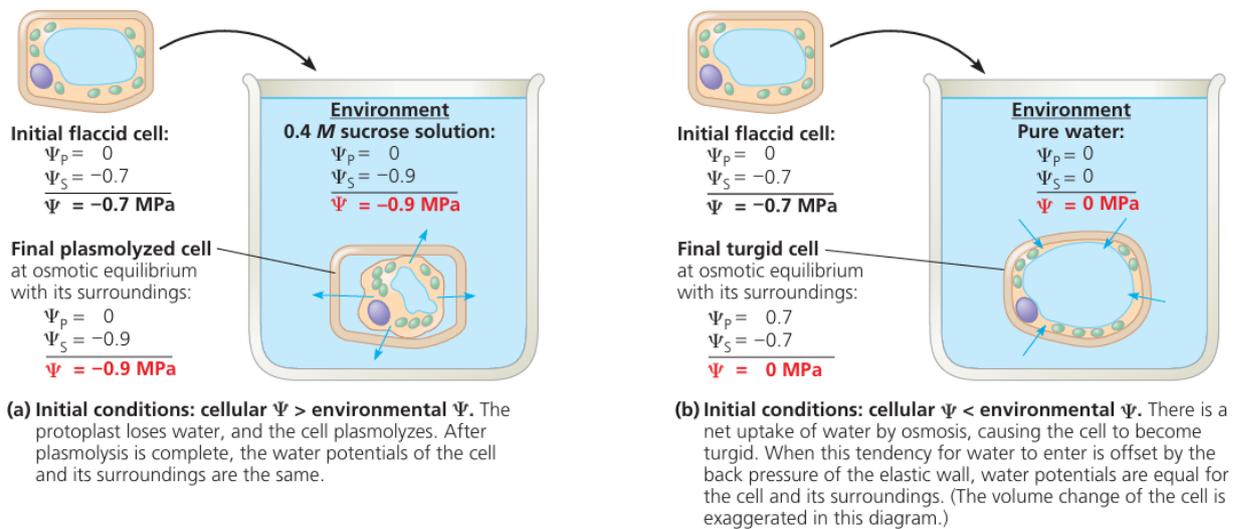
figure 71. The effect of water potential on the absorption and loss of water by a living plant cell

Aquaporins: Facilitating Diffusion of Water:

Differences in water potential (Ψ) determine the direction of water movement across membranes — but how do water molecules cross membranes?

Water molecules are small enough to diffuse through the phospholipid bilayer, even though the inner region of the bilayer is hydrophobic. However, their movement across biological membranes is too rapid to be explained by unaided diffusion alone. Transport proteins called aquaporins facilitate the movement of water molecules across the plasma membranes of plant cells. Aquaporin channels, which can open and close, regulate the rate of osmotic water movement across the membrane. This permeability decreases when there is an increase in cytosolic Ca^{2+} concentration or a decrease in cytosolic pH.

The apoplast and Symplast: transport Continuums:

Plasmodesmata	Symplast	Apoplast
the cytoplasmic channels that connect these cells to one another.	consists of the entire mass of cytosol of all the living cells in a plant,	consists of everything external to the plasma membranes of living cells, including the cell walls, extracellular spaces, and the interiors of dead cells, such as

		xylem vessel elements and tracheids.
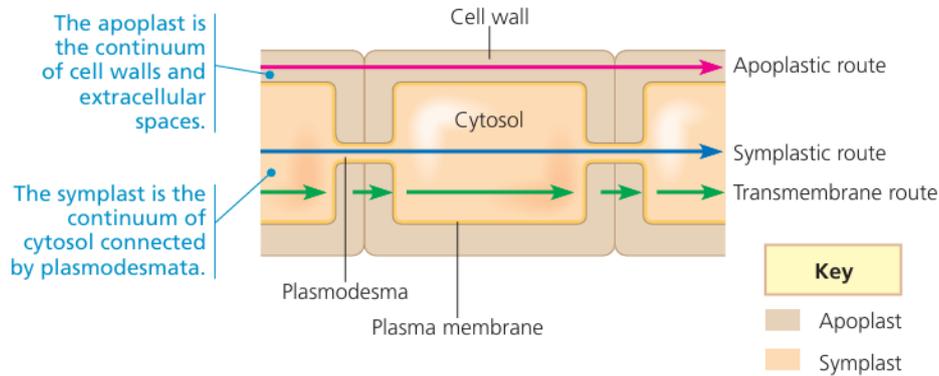
figure 72. Cell compartments and routes for short-distance transport

Long-Distance transport: the role of Bulk Flow:

Long-distance transport occurs through bulk flow, which is the movement of a fluid in response to a pressure gradient. Bulk flow of substances always occurs from regions of higher pressure to regions of lower pressure. Unlike osmosis, bulk flow is independent of solute concentration. Bulk flow over long distances take place within the specialized cells of the vascular tissues — the tracheid's and vessel elements of the xylem, and the sieve-tube elements of the phloem.

Transpiration drives the transport of water and minerals from roots to shoots via the xylem:

The absorption and transport of water and minerals through the xylem occur in three stages

Absorption of Water and minerals by root Cells	Transport of Water and minerals into the Xylem	Bulk Flow transport via the Xylem
1. Osmosis 2. Active Transport	1. Symplast. 2. Apoplast	1. Pushing Xylem Sap: Root Pressure 2. Pulling Xylem Sap: The Cohesion-Tension Hypothesis.
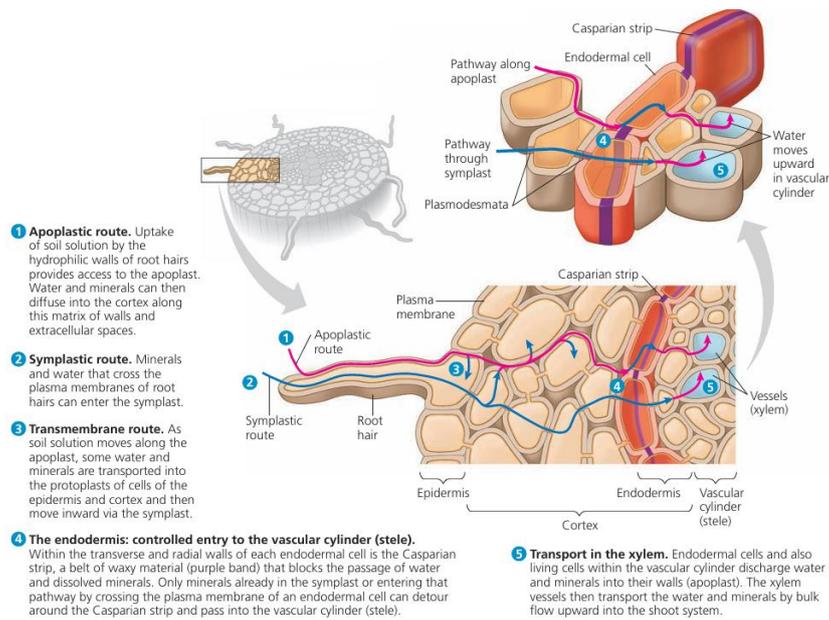
Figure 73. Transport of water and minerals from root hairs to the xylem

Ascent of xylem sap

Ascent of xylem sap. Hydrogen bonding forms an unbroken chain of water molecules extending from leaves to the soil. The force driving the ascent of xylem sap is a gradient of water potential (Ψ). For bulk flow over long distance, the Ψ gradient is due mainly to a gradient of the pressure potential (ΨP). Transpiration results in the ΨP at the leaf end of the xylem being lower than the ΨP at the root end.
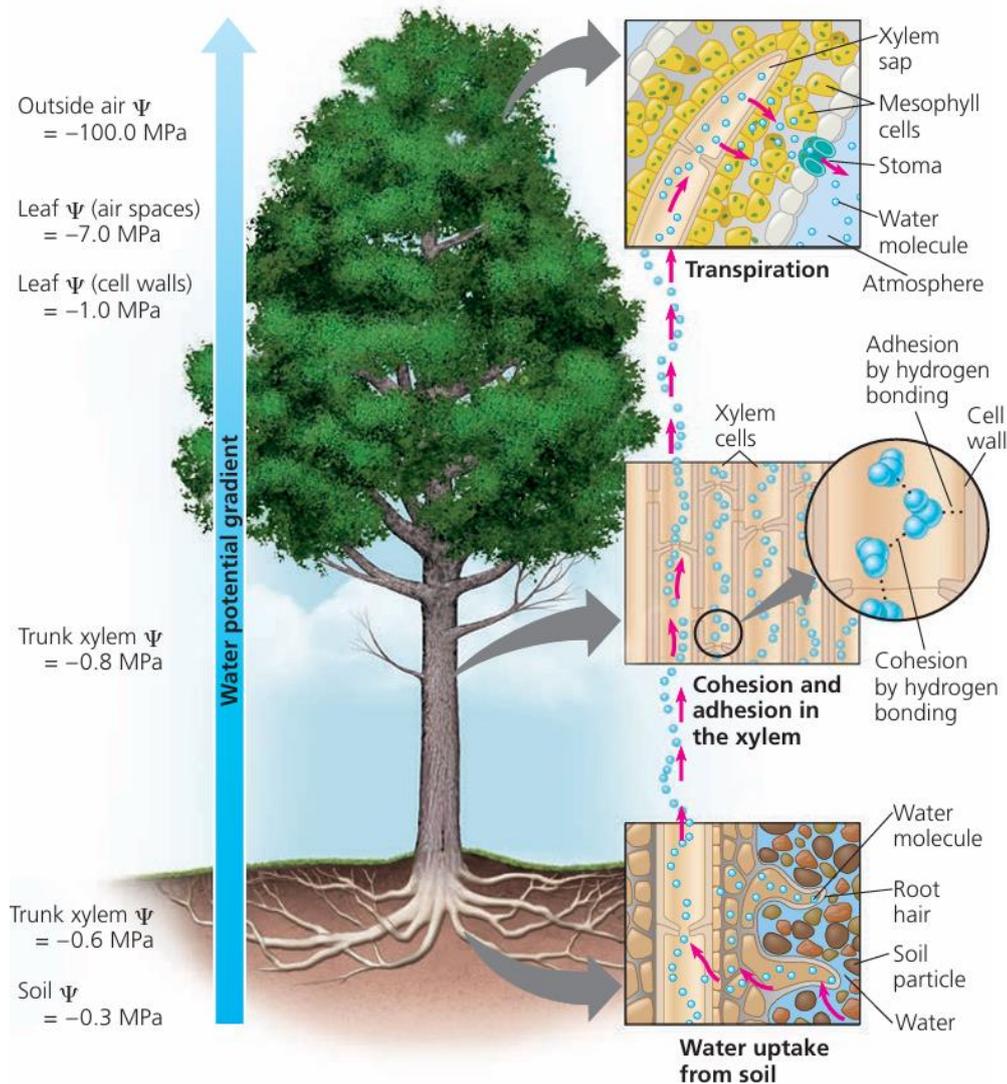
figure 74. Ascent of xylem sap

The rate of transpiration is regulated by stomata

- Stomata: major Pathways for Water Loss
- Mechanisms of Stomatal opening and Closing
- Stimuli for Stomatal opening and Closing

Guard cells turgid/Stoma open   Guard cells flaccid/Stoma closed   Guard cells turgid/Stoma open   Guard cells flaccid/Stoma closed
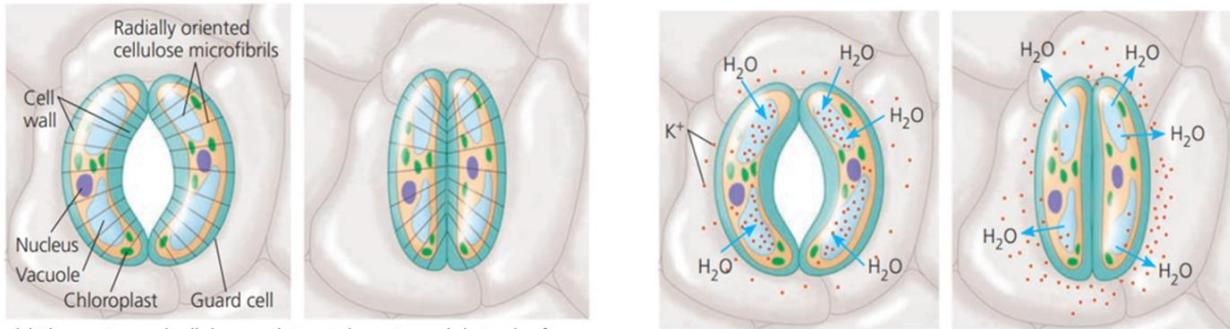
(a) Changes in guard cell shape and stomatal opening and closing (surface view). Guard cells of a typical angiosperm are illustrated in their turgid (stoma open) and accid (stoma closed) states. The radial orientation of cellulose micro-brils in the cell walls causes the guard cells to increase more in length than width when turgor increases. Since the two guard cells are tightly joined at their tips, they bow outward when turgid, causing the stomatal pore to open.

(b) Role of potassium ions (K+) in stomatal opening and closing. The transport of K+ (symbolized here as red dots) across the plasma membrane and vacuolar membrane causes the turgor changes of guard cells. The uptake of anions, such as malate and chloride ions (not shown), also contributes to guard cell swelling.

figure 75. Mechanisms of stomatal opening and closing

Adaptations that reduce Evaporative Water Loss:

Xerophytes have unusual physiological or morpho logical adaptations that enable them to withstand harsh desert conditions. The stems of many xerophytes are fleshy because they store water for use during long dry periods. Cacti have highly reduced leaves that resist excessive water loss; photo synthesis is carried out mainly in their stems. Another adaptation common in arid habitats is crassulacean acid metabolism (CAM), a specialized form of photosynthesis found in succulent's plants. Because the leaves of CAM plants take in CO2
at night, the stomata can remain closed during the day, when evaporative stresses are greatest.

- Sugars are transported from sources to sinks via the phloem:
- Sugar is transported through the phloem in two stages

Movement from Sugar Sources to Sugar Sinks	Bulk Flow by Positive Pressure
1. Symplast 2. Apoplast 3. Active transport	The uptake of water from the xylem into the phloem generates a positive pressure within the phloem elements.

Mesophyll cell
Cell walls (apoplast)
Plasma membrane
Plasmodesmata
Companion (transfer) cell
Sieve-tube element
Mesophyll cell
Bundle-sheath cell
Phloem parenchyma cell

Key
Apoplast
Symplast

(a) Sucrose manufactured in mesophyll cells can travel via the symplast (blue arrows) to sieve-tube elements. In some species, sucrose exits the symplast near sieve tubes and travels through the apoplast (red arrow). It is then actively accumulated from the apoplast by sieve-tube elements and their companion cells.

High H+ concentration
Cotransporter
Proton pump
Low H+ concentration
ATP
Sucrose

(b) A chemiosmotic mechanism is responsible for the active transport of sucrose into companion cells and sieve-tube elements. Proton pumps generate an H+ gradient, which drives sucrose accumulation with the help of a cotransport protein that couples sucrose transport to the diffusion of H+ back into the cell.

figure 76. Loading of sucrose into phloem.

Vessel (xylem)
Sieve tube (phloem)
Source cell (leaf)
H₂O
Sucrose
H₂O
Bulk flow by negative pressure
Bulk flow by positive pressure
Sink cell (storage root)
Sucrose
H₂O

❶ Loading of sugar (green dots) into the sieve tube at the source (in this example, a mesophyll cell in a leaf) reduces water potential inside the sieve-tube elements. This causes the tube to take up water by osmosis.

❷ This uptake of water generates a positive pressure that forces the sap to flow along the tube.

❸ The pressure is relieved by the unloading of sugar and the consequent loss of water at the sink.

❹ In leaf-to-root translocation, xylem recycles water from sink to source.

figure 77. Bulk flow by positive pressure in a sieve tube.

Chapter Three

Soil and Plant Nutrition
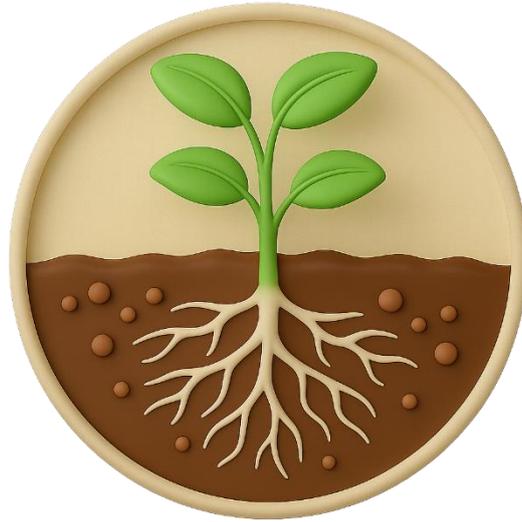
Soil contains a living, complex ecosystem

The upper layers of the soil, from which plants absorb nearly all the water and minerals they require, contain a wide range of living organisms that interact with each other and with the physical environment.

Essential elements:

The inorganic substances in plants contain more than 50 chemical elements. When studying the chemical composition of plants, it is important to distinguish between essential elements and those that are merely present in the plant. A chemical element is considered an essential element only if it is required for the plant to complete its life cycle and reproduce.

nutrients	CO_2	O_2	H_2O	NO_3^- ,NH_4^+	K^+	Ca^{2+}	Mg^{2+}	H_2PO^{4-}	SO^{4-}
Symptom(s) of nutrient Deficiencies	Poor growth	Poor growth	Wilting, poor growth	Chlorosis at tips of older leaves	Mottling of older leaves weak stems; roots	Crinkling of young leaves; death of terminal buds	Chlorosis between veins	slow develop-ment; thin stems	chlorosis in young leaves

Plant nutrition often involves relationships with other organisms:

Up to this point, we have described plants as exploiters of soil resources, but the relationship between plants and soil is a two-way relationship. Dead plants provide much of the energy needed by bacteria and fungi living in the soil. Many of these organisms also benefit from the sugar-rich secretions produced by living roots. At the same time, plants benefit from their associations with soil bacteria and fungi.

The roles of soil bacteria in the nitrogen nutrition of plants:

Ammonium is made available to plants by two types of soil bacteria: those that fix atmospheric N2 (nitrogen-fixing bacteria) and those that decompose organic material (ammonifying bacteria). Although plants absorb some ammonium from the soil, they absorb mainly nitrate, which is produced from ammonium by nitrifying bacteria.
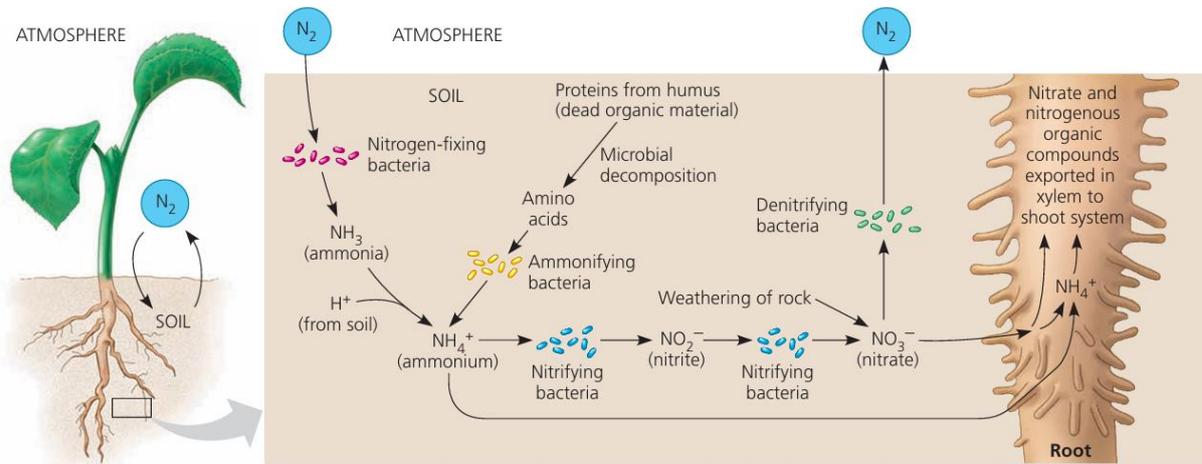
figure 78. The roles of soil bacteria in the nitrogen Fixation

Rhizobacteria

Development of a soybean root nodule:
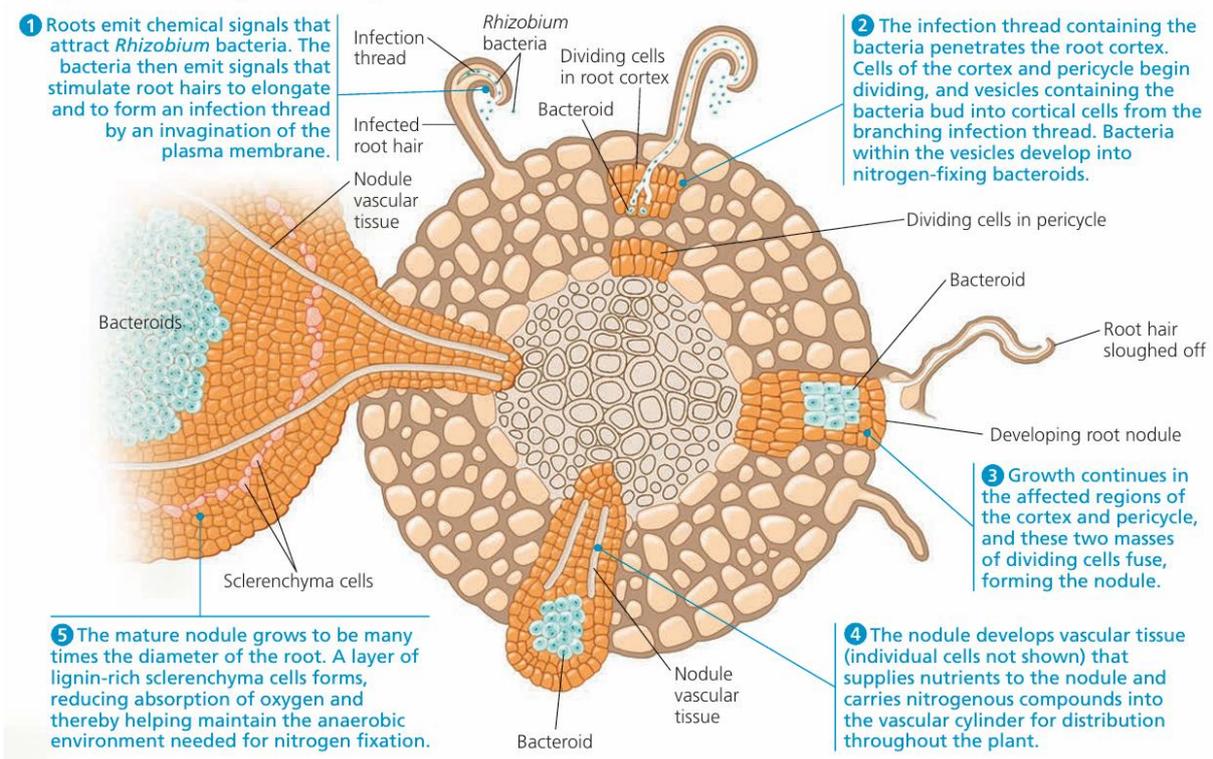
Figure 79. Development of a soybean root nodule

Fungi and Plant nutrition

Arbuscular mycorrhizae (Endomycorrhizae)	Ectomycorrhizae.
No mantle forms around the root, but microscopic fungal hyphae extend into the root. Within the root cortex, the fungus makes extensive contact with the plant through branching of hyphae that form arbuscules, providing an enormous surface area for nutrient swapping. The hyphae penetrate the cell walls, but not the plasma membranes, of cells within the cortex.	The mantle of the fungal mycelium ensheathes the root. Fungal hyphae extend from the mantle into the soil, absorbing water and minerals, especially phosphorus. Hyphae also extend into the extracellular spaces of the root cortex, providing extensive surface area for nutrient exchange between the fungus and its host plant.
Figure 80. Endomycorrhizae	Figure 81 Ectomycorrhizae.
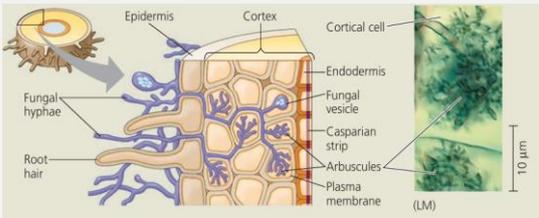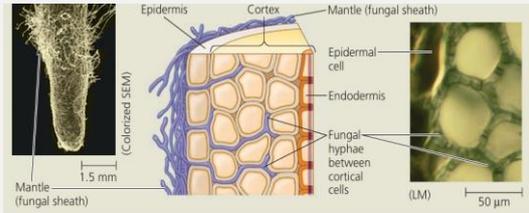
Unusual nutritional adaptations in Plants

1. Epiphytes
2. Parasitic Plants
3. Carnivorous Plants

figure 82. From the left (Carnivorous, Parasitic and Epiphytes)

Chapter Four

Angiosperm Reproduction

⬛ **Flowers, double fertilization, and fruits are key features of the angiosperm life cycle**

The life cycles of all plants are characterized by an alternation of generations, in which multicellular haploid (n) and multicellular diploid (2n) generations alternately produce each other. Fertilization, the fusion of gametes, results in a diploid zygote, which divides by mitosis and forms a new sporophyte. In angiosperms, the sporophyte is the dominant generation: It is larger, more conspicuous, and longer-lived than the gametophyte. The key traits of the angiosperm life cycle can be remembered as the "three Fs"—flowers, double fertilization, and fruits.

Flower Structure and Function:

The flower, which is the sporophytic structure in angiosperms specialized for sexual reproduction, is typically composed of four types of floral organs: carpels, stamens, petals, and sepals (see figure). The carpel (also called a megasporophyll) contains an ovary at its base and a slender neck called the style. At the top of the style is a sticky structure known as the stigma, which functions to capture pollen grains. The stamen (also called a microsporophyll) consists of a stalk called the filament and a terminal structure called the anther. Inside the anther are chambers known as microsporangia or pollen sacs, which produce pollen grains.
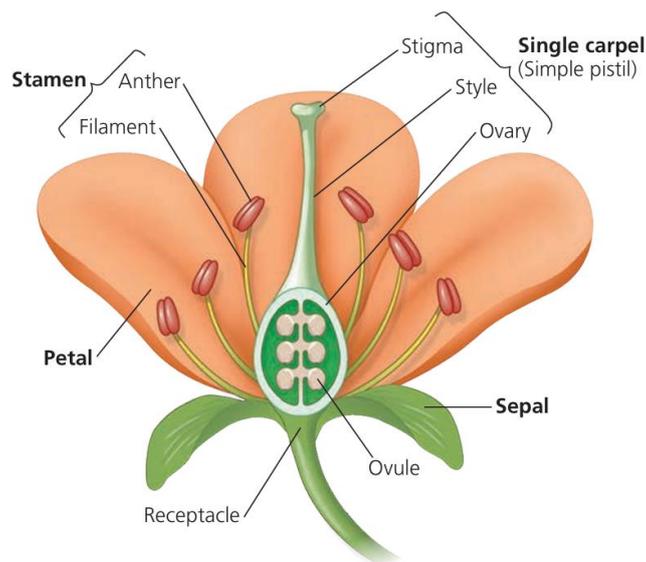
Figure 83. The structure of an idealized flower

Methods of Pollination

Pollination by Bees	Pollination by Wind

The flowers have attractive colors and fragrances.

floral structures can create eddy currents that aid in pollen capture

Pollination by Bats	Pollination by Moths and Butterflies

Bat-pollinated flowers, and the flowers, are light colored and aromatic

Anther
Moth
Stigma

the flowers they pollinate are often sweetly fragrant. And they are usually white or yellow,

Pollination by Birds	Pollination by Flies

Hummingbird drinking nectar of columbine flower

flowers, are usually large and bright. The petals of such flowers are often fused, forming a bent floral tube that fits the curved beak of the bird.

Blowfly

flowers are reddish and fleshy, with an odor like rotten meat.

The life cycle of angiosperms:

Pollination is one step in the angiosperm life cycle. Figure below provides a complete overview of the life cycle, focusing on gametophyte development, sperm delivery by pollen tubes, double fertilization, and seed development. Over the course of seed plant evolution, gametophytes became reduced in size and wholly dependent on the sporophyte for nutrients (see Figure 30.2). The gametophytes of angiosperms are the most reduced of all plants, consisting of only a few cells: They are microscopic, and their development is obscured by protective tissues. For simplicity, a flower with a single carpel (simple pistil) is shown. Many species have multiple carpels, either separate or fused
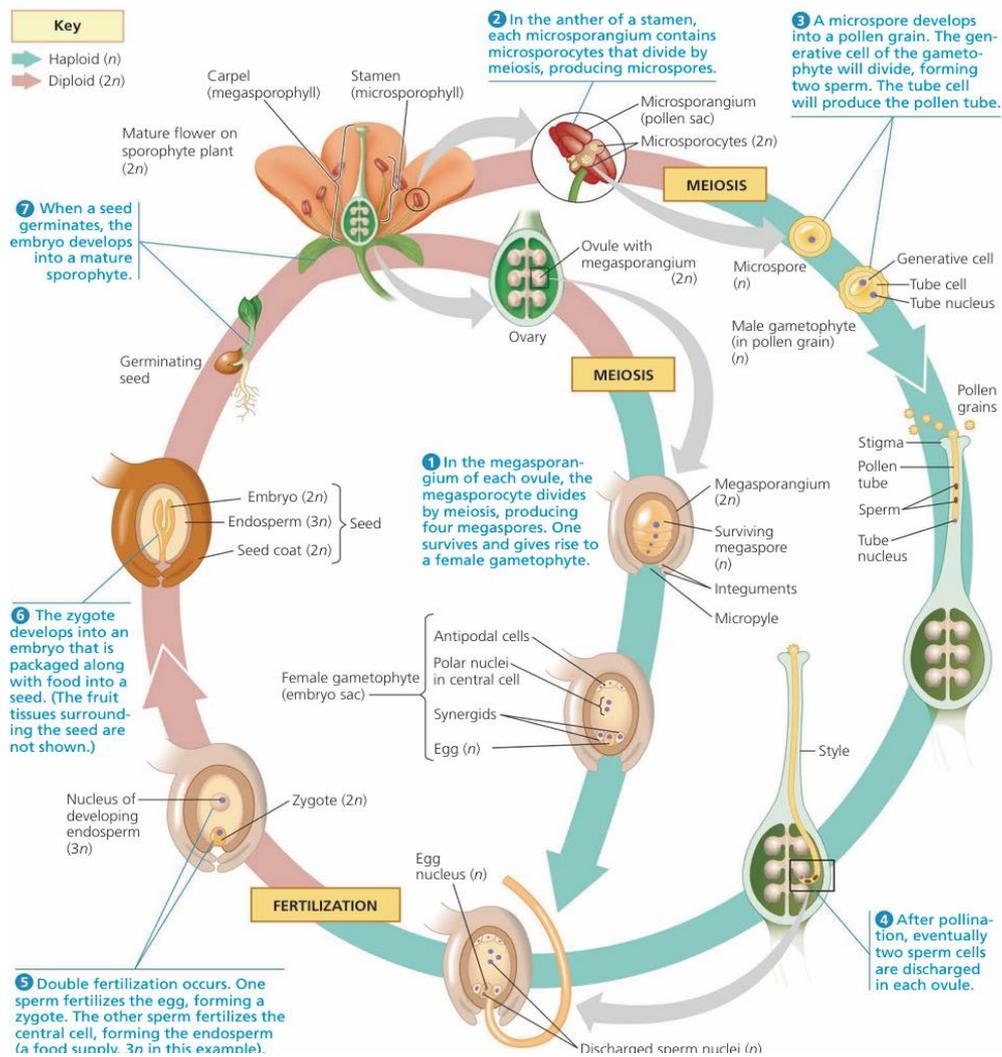
Figure 84. The life cycle of angiosperms

Seed Development and Structure:

Seed formation goes through three stages:

1. Endosperm Development:

Endosperm usually develops before the embryo does. After double fertilization, the triploid nucleus of the ovule's central cell divides, forming a multinucleate "supercell" that has a milky consistency. This liquid mass, the endosperm, becomes multicellular when cytokinesis partitions the cytoplasm by forming membranes between the nuclei. Eventually, these "naked" cells produce cell walls, and the endosperm becomes solid.

2. Embryo Development:

By the time the ovule becomes a mature seed, and the integuments harden and thicken into the seed coat, the zygote has given rise to an embryonic plant with rudimentary organs.

3. Mature Seed:

During the last stages of its maturation, the seed dehydrates until its water content is only about 5–15% of its weight. The embryo, which is surrounded by a food supply (cotyledons, endosperm, or both), enters dormancy; that is, it stops growing and its metabolism nearly ceases
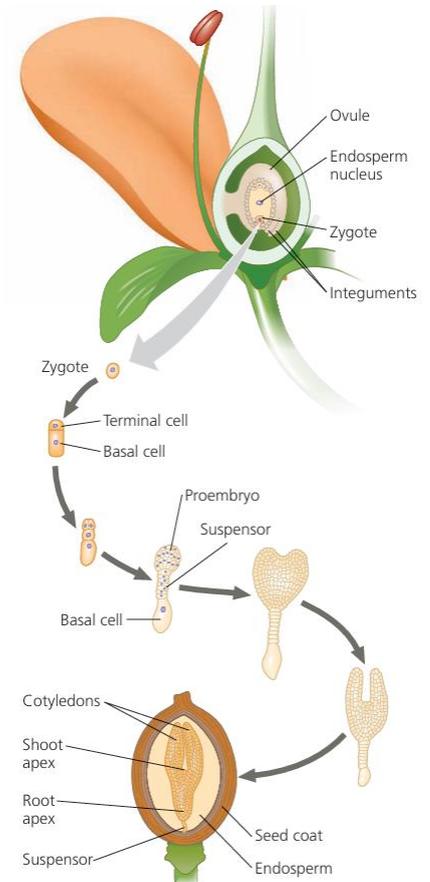
Figure 85. The development of a eudicot plant embryo
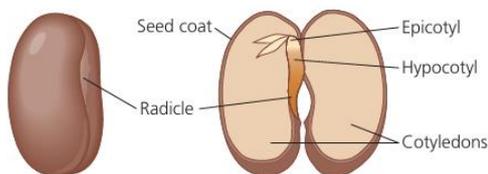
Figure 86. Seed structure in eudicot
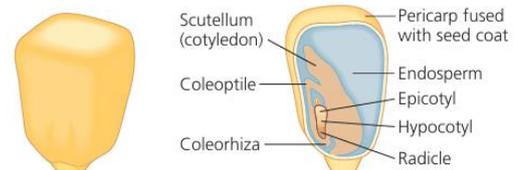
Figure 87. Seed structure in monocot

Seed Germination

When environmental conditions are favorable for growth, dormancy in the seeds is broken and germination continues. Germination is followed by the growth of stems, leaves, and roots, and eventually flowering.

Maize.	Common garden bean.
In maize and other grasses, the shoot grows straight up through the tube of the coleoptile.	In common garden beans, straightening of a hook in the hypocotyl pulls the cotyledons from the soil.
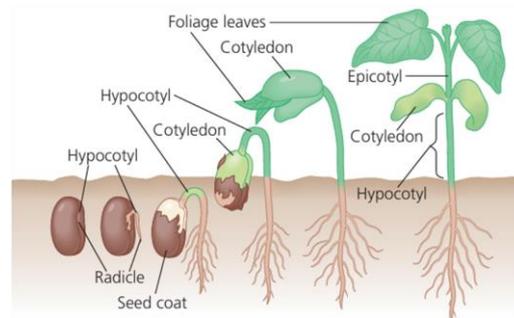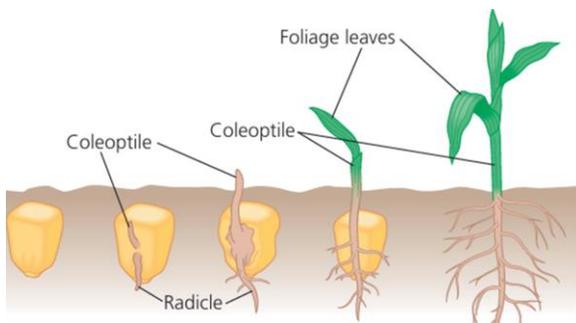
Figure 88. Stages of seed germination in monocots and dicots

Fruit Structure and Function:

Aggregate fruit	Simple fruit
develops from many separate carpels of one flower	develops from a single carpel (or several fused carpels) of one flower

Accessory fruit	Multiple fruit

develops largely from tissues other than the ovary	develops from many carpels of the many flowers that form an inflorescence
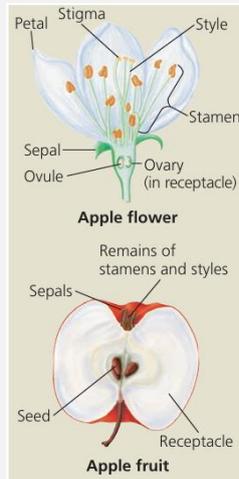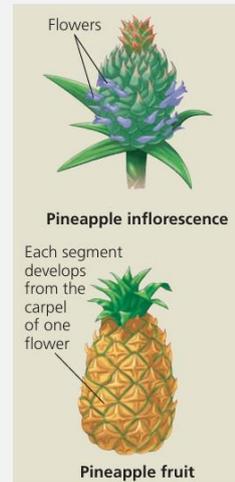
☞ Fruit and Seed Dispersal

Dispersal by Wind

- With a wingspan of 12 cm, the giant seed of the tropical Asian climbing gourd *Alsomitra macrocarpa* glides through the air of the rain forest in wide circles when released
- Some seeds and fruits are attached to umbrella like" parachutes" that are made of intricately branched hairs.
- Tumbleweeds break off at the ground and tumble across the terrain, scattering them seeds.
- The winged fruit of a maple spins like a helicopter blade, slowing descent and increasing the chance of being carried farther by horizontal winds.

Dispersal by Water

- Some buoyant seeds and fruits can survive months or years at sea. In coconut, the seed embryo and fleshy white "meat" (endosperm) are within a hard layer (endocarp) surrounded by a thick and buoyant fibrous husk.

Dispersal by Animals

- The sharp, tack-like spines on the fruits of puncture vine (Tribulus terrestris) can pierce bicycle tires and injure animals, including humans. When these painful" tacks" are removed and discarded, the seeds are dispersed.
- Some animals, such as squirrels, hoard seeds or fruits in underground caches. If the animal dies or forgets the cache's location, the buried seeds are well positioned to germinate.

Figure 89. fruits of (Tribulus)

Figure 90. Desert grass plants

Figure 91. Seed of the tropical Asian climbing gourd

Figure 92. Fruit of a maple spins

Figure 93. Seeds and fruits are attached to umbrella

Chapter Five

Plant Responses to Signals
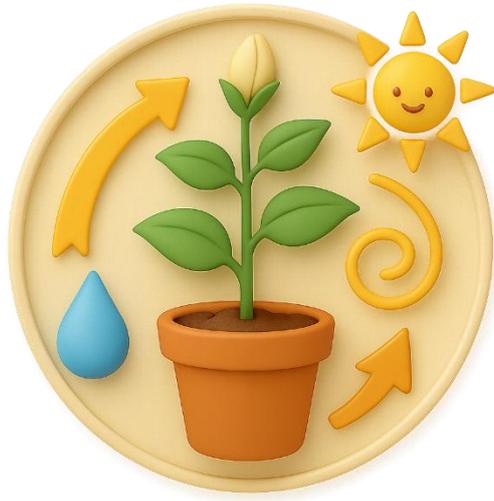
Plant hormones help coordinate growth, development, and responses to stimuli

A hormone, in the original meaning of the term, is a signaling molecule that is produced in low concentrations by one part of an organism's body and transported to other parts, where it binds to a specific receptor and triggers responses in target cells and tissues.

Study of plant hormones:

The major plant hormones are auxins, cytokinins, gibberellins, abscisic acid, ethylene, brassinosteroids, jasmonates, and strigolactones.

Auxin:

1. Charles Darwin and his son Francis
2. The role of auxin in Cell elongation
3. Auxin's role in Plant Development

Cytokinins:

1. Control of Cell Division and Differentiation
2. Control of apical Dominance
3. Anti-aging effects

Inquiry What part of a grass coleoptile senses light, and how is the signal transmitted?

Experiment In 1880, Charles and Francis Darwin removed and covered parts of grass coleoptiles to determine what part senses light. In 1913, Peter Boysen-Jensen separated coleoptiles with different materials to determine how the signal for phototropism is transmitted.

Results
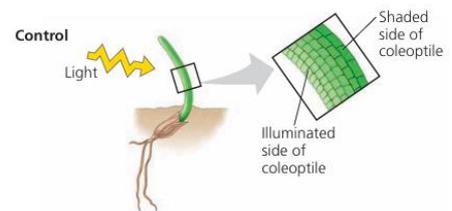
Darwin and Darwin: Phototropism occurs only when the tip is illuminated.
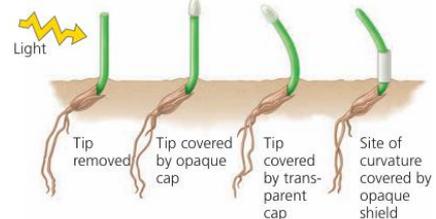
Boysen-Jensen: Phototropism occurs when the tip is separated by a permeable barrier but not an impermeable barrier.
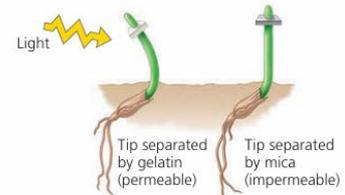
Data from C. R. Darwin, The power of movement in plants, John Murray, London (1880). P. Boysen-Jensen, Concerning the performance of phototropic stimuli on the Avenacoleoptile, *Berichte der Deutschen Botanischen Gesellschaft* (*Reports of the German Botanical Society*) 31:559–566 (1913).

Conclusion The Darwins' experiment suggested that only the tip of the coleoptile senses light. The phototropic bending, however, occurred at a distance from the site of light perception (the tip). Boysen-Jensen's results suggested that the signal for the bending is a light-activated mobile chemical.

Figure 94. Effects on apical dominance of removing the apical bud.

Figure 95. Charles and Francis Darwin experiment

◻ Gibberellins

1. Stem elongation

2. Fruit Growth

3. Germination

❶ After a seed imbibes water, the embryo releases gibberellin (GA), which sends a signal to the aleurone, the thin outer layer of the endosperm.

❷ The aleurone responds to GA by synthesizing and secreting digestive enzymes that hydrolyze nutrients stored in the endosperm. One example is α-amylase, which hydrolyzes starch.

❸ Sugars and other nutrients absorbed from the endosperm by the scutellum (cotyledon) are consumed during growth of the embryo into a seedling.

Aleurone
Endosperm
α-amylase
Sugar
GA
GA
Water
Radicle
Scutellum (cotyledon)

(a) Some plants develop in a rosette form, low to the ground with very short internodes, as in the *Arabidopsis* plant shown at the left. As the plant switches to reproductive growth, a surge of gibberellins induces bolting: Internodes elongate rapidly, elevating floral buds that develop at stem tips (right).

(b) The Thompson seedless grape bunch on the left is from an untreated control vine. The bunch on the right is growing from a vine that was sprayed with gibberellin during fruit development.

Figure 96. Mobilization of nutrients by gibberellins during the germination of grain seeds such as barley.

Figure 97. Effects of gibberellins on stem elongation and fruit growth.

◻ Abscisic Acid:

1. Seed Dormancy

2. Drought tolerance

◻ Ethylene:

1. The triple response to mechanical Stress

2. Senescence

3. Leaf abscission

4. Fruit ripening

◻ More Recently Discovered Plant Hormones:

1. Brassinosteroids

2. Jasmonates

3. Strigolactones

	Exercises
1	Which of the following is correctly paired with its structure and function?
A	Sclerenchyma—supporting cells with thick secondary walls
B	Ground meristem—protective coat of woody stems and roots
C	Guard cells—waterproof ring of cells surrounding the central stele in roots
D	Periderm—parenchyma cells functioning in photosynthesis in leaves
2	Which of the following is the correct sequence of the zones in the primary growth of a root, moving from the root cap inward?
A	Zone of cell division, zone of elongation, zone of differentiation.
B	Zone of differentiation, zone of elongation, zone of cell division
C	Zone of elongation, zone of cell division, zone of differentiation
D	Zone of cell division, zone of differentiation, zone of elongation

3	The veins of leaves are _____.
	
	   I. Composed of xylem and phloem
	
	   II. Continuous, with vascular bundles in the stem and roots
	
	   III. Finely branched to be in close contact with photosynthesizing cells

A	B	C	D
only I	only II	only III	I, II, and III

4	The main function associated with structure X is _____.
A	Absorption of carbon dioxide
B	Retention of water
C	Collection of light
D	Release of carbon dioxide
5	Which of the following would be least likely to affect osmosis in plants?
A	A difference in solute concentrations.
B	Receptor proteins in the membrane
C	Aquaporins.
D	A difference in water potential
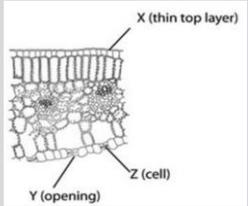
6	If isolated plant cells with a water potential averaging –0.5 MPa are placed into a solution with a water potential of –0.3 MPa, which of the following would be the most likely outcome?
A	The pressure potential of the cells would increase
B	Water would move out of the cells
C	The cell walls would rupture, killing the cells.
D	Solutes would move out of the cells.

7	Arrange the following five events in an order that explains the mass flow of materials in the phloem. 1. Water diffuses into the sieve tubes. 2. Leaf cells produce sugar by photosynthesis. 3. Solutes are actively transported into sieve tubes. 4. Sugar is transported from cell to cell in the leaf. 5. Sugar moves down the stem.

A	B	C	D
1, 2, 3, 4, 5	2, 4, 3, 1, 5	4, 2, 1, 3, 5	2, 4, 1, 3, 5

8	The value for Ψ in root tissue was found to be –0.15 MPa. If you take the root tissue and place it in a 0.1 M solution of sucrose (Ψ = –0.23 MPa), the net water flow would _____.
A	be from the tissue into the sucrose solution
B	be from the sucrose solution into the tissue
C	be in both directions, and the concentration of water would remain equal
D	be impossible to determine from the values given here

9	If an ovary contains 50 ovules, what is the minimum number of pollen grains that must land to form 50 mature seeds?

A	B	C	D
25	50	100	500

10	Which of the following is a primary difference between ectomycorrhizae and endomycorrhizae?
A	Endomycorrhizae have thicker, shorter hyphae than ectomycorrhizae.
B	Ectomycorrhizae do not penetrate root cells, whereas endomycorrhizae grow into invaginations of the root cell membranes.

C	Endomycorrhizae are more common than ectomycorrhizae
D	There are no significant differences between ectomycorrhizae and endomycorrhizae.
11	Some dioecious species have the XY genotype for male and XX for female. After double fertilization, what would be the genotypes of the embryos and endosperm nuclei?
A	embryo XY/endosperm XXX or embryo XX/endosperm XXY
B	embryo XX/endosperm XX or embryo XY/endosperm XY.
C	embryo XX/endosperm XXX or embryo XY/endosperm XYY.
D	embryo XX/endosperm XXX or embryo XY/endosperm XXY
12	What adaptations should one expect of the seed coats of angiosperm species whose seeds are dispersed by frugivorous (fruit-eating) animals, as opposed to angiosperm species whose seeds are dispersed by other means? 1. The exterior of the seed coat should have barbs or hooks. 2. The seed coat should contain secondary compounds that irritate the lining of the animal's mouth. 3. The seed coat should be able to withstand low pHs. 4. The seed coat, upon its complete digestion, should provide vitamins or nutrients to animals. 5. The seed coat should be resistant to the animals' digestive enzymes.

A	B	C	D
4 only	1 and 2	3 and 5	3,4, and 5

13	Which of the following mechanisms is the correct sequence of events that takes place during the plant responses to internal and external signals?
A	transduction, reception, and response
B	reception and transduction
C	reception, transduction, and response
D	reception and response
14	Plant hormones produce their effects by _____. I. altering the expression of genes II. modifying the permeability of the plasma membrane III. modifying the structure of the nuclear envelope membrane?

A	B	C	D
Only I	Only II	Only III	Only I and II

1- The diagram shows the water potentials of 3 adjacent plant cells (the water potential of pure water is 0).
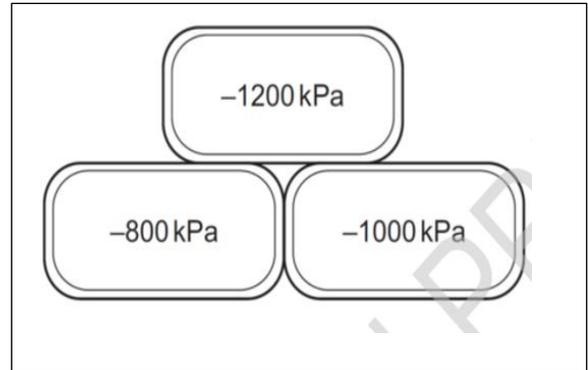
Determine for each of the following figures whether the direction of water movement due to osmosis is depicted correctly?

A	B	C	D
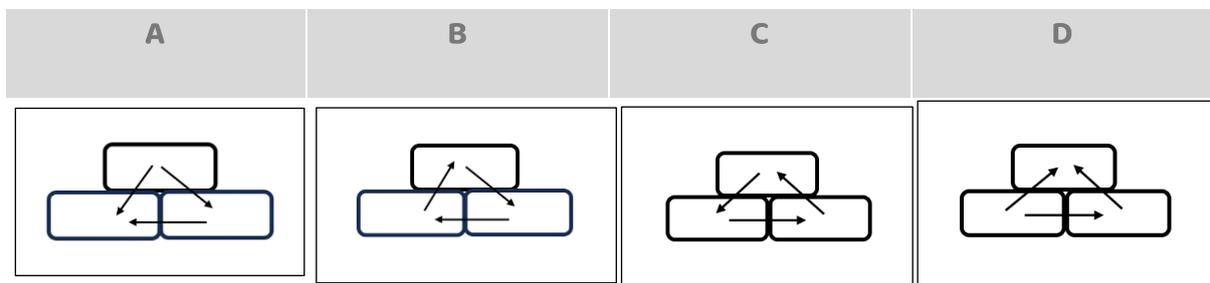
2- On a warm summer's day, the transpiration pull is the main force that drives water from root parenchyma into the root xylem. The table shows values of ψ_p (pressure potential) and ψ_s (solute potential) in root xylem and root parenchyma, in kPa.

In which of the following options would transpiration pull cause water to move from root parenchyma into the root xylem?

	Root parenchyma		Root xylem	
	Ψ_p	Ψ_s	Ψ_p	Ψ_s
A	200	–190	–200	5
B	–200	220	65	–5
C	200	–220	65	–5
D	200	–220	–65	–5

3- Identify the likely seed characteristics for the two seeds that depend on different dispersal mechanisms. The first seed depends on wind dispersal and the second on dispersal via ruminants.

	Wind dispersed seed	Seed dispersed via ruminant
A	Dense nut with woody pericarp	Very light , spiral feathers
B	Small dense pip in ballistic pod under tension	Multiple fine hairs coat the outside with hooks
C	Dense fire-resistant seed coat	Fleshy fruit coated in small seeds
D	Rotary wing, small	Drupe fruit, colored, hard inner seed coat

4- Plant tissues where carbon fixation occurs are known as 'source'. The product(s) formed is/are then transported to different parts of the plant body for its further utilization or storage, which is known as 'sink.'

Which of the following can be categorized as 'source (P)'and 'Sink (Q)?'

A- (P) endodermis of root; (Q) phloem cells of root

B- (P) epidermal region of assimilatory root; (Q) meristematic region of assimilatory root

C- (P) parenchyma of beet tuber; (Q) phloem cells of root

D- (P) xylem tissue of a green leaf; (Q) phloem tissue of the adjacent green leaf

5- The ABC-model of flower development explains the regulation of whorl differentiation in flower meristems.

There are three groups of master genes, A, B and C genes, each determining a type of whorl:

- Sepals need only A gene expression.
- Petals need simultaneous expression of A and B genes.
- Stamens need simultaneous expression of B and C genes.
- Carpels need only C gene expression.

X	ABC - model
Y	Lacandonia flower

- The tropical American plant, *Lacandonia schismatica*,

  has inverted flowers (see Figure), with stamens located in the center of flower, and individual carpels located between petals and stamens True or false?

	Statements	T or F
1	*Lacandonia schismatica* flower morphology could be explained by gene expression pattern I	
2	Flowers of *Lacandonia schismatica* would have neither petals nor carpels, if flowers followed gene expression pattern II	
3	The only whorls flowers of *Lacandonia schismatica* would be missing, if they followed expression pattern III, is petal	
4	petals, like sepals, need only A gene expression.	

6- The picture below shows the steps of the collapse of xylem vessels in plants. What is the correct explanation for such a collapse?
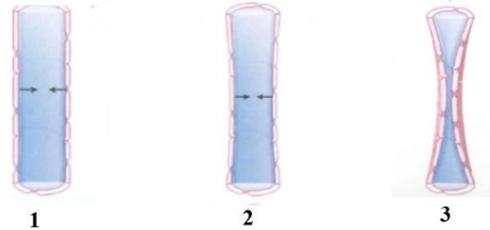
A	Deficient in lignin on cell walls.
B	Increasing the concentration of solutes in xylem sap
C	Shifting the transmission mechanism from negative pressure to positive pressure
D	Many water bubbles collect inside xylem vessels

7- The following schematic image shows the transverse cut of root showing symbiosis with 3 different groups of organisms (a, b, and c).
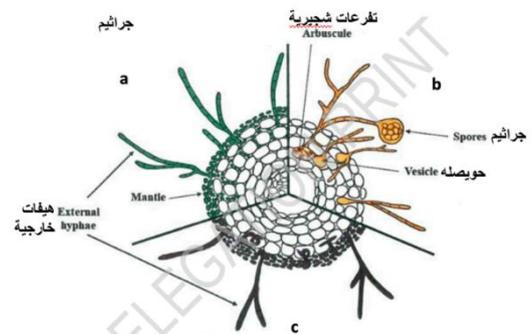
Using the schematic image, determine whether the following statements are true or false.

	Statements	T or F
A	Diagram (a) shows ectomycorrhiza.	
B	Diagram (b) shows endomycorrhiza.	
C	Diagram (c) shows ectendomycorrhiza.	
D	One of the diagrams indicates a symbiosis of nitrogen-fixing bacteria and plant.	

8- Many climbing plants have tendrils, a thread-like organ specialized for winding around or clinging to a support. While tendrils are typically modified leaves, some tendrils are modified stems, which can be distinguished by morphological inspection.

For a tendril sample, answer which of the following observations is most informative for judging whether it is a modified leaf or a modified stem.

Mark true or false in the appropriate box.

Vicia sativa

Cayratia japonica

1	Observation of the surface to examine the presence/absence of stomata	
2	Observation of the surface to examine the thickness of the cuticular wax layer	
3	Observation of the surface to examine the shape of epidermal cells	
4	Observation of the cross section to examine the positional arrangement of the xylem and phloem	
5	Observation of the inner tissue to examine the presence/absence of developed chloroplasts	

9- Ali found a permanent slide in an old cupboard of his school laboratory. As the corner of the slide was broken, the label was incomplete. He could only read 'T.S. of....' He started observing the slide under the microscope. He observed the section as shown in the picture below.
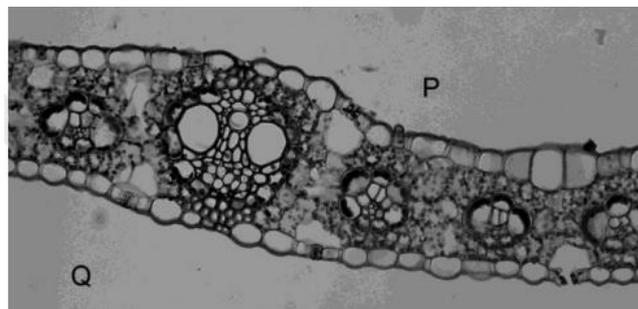
i	It is a transverse section of a floating hydrophytic leaf.
ii	The epidermal region towards 'P' can be considered as the adaxial side.
iii	The plant must be monocotyledonous.
iv	If water dries up, the leaf will curl downwards towards 'Q'.
v	There is no prominent mid-vein present in this leaf.

a. ii only

b. i and iv

c. ii and iii

d. iii, iv and v

10- The following figure shows a cross section of the root of Ranunculus (buttercup) describing the organization of primary tissues in young roots. This root cross section represents basic pattern of root organization. What is the name of the root tissue indicated by the question mark?.
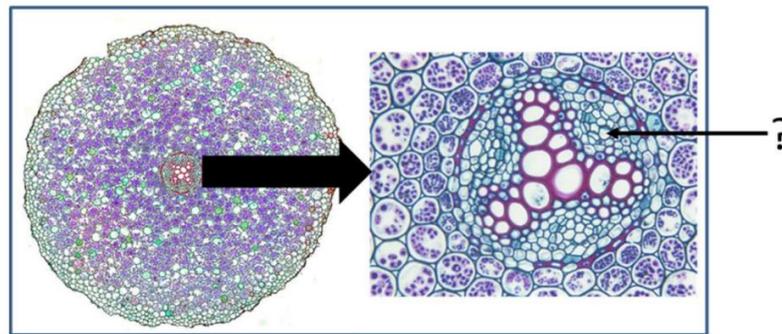
Cross section of the root of *Ranunculus* (buttercup).

A	B	C	D
Phloem	Cortex	Xylem	Endodermis

Answer key for exercises

1	A	8	A
2	A	9	B
3	D	10	C
4	C	11	D
5	B	12	C
6	A	13	C
7	B	14	D

Answer key for the Mock Exam

1	D			
2	D			
3	D			
4	B			
5	T	F	F	T
6	A			
7	T	T	T	F
8	F	F	F	T	F
9	C			
10	A			

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Chemistry

Stoichiometry Calculations
<div dir="rtl">

حسابات المعادلات الكيميائية
</div>

<div dir="rtl">

يمكن الاستفادة من المعادلة الكيميائية في إجراء الحسابات الخاصة بكميات المواد المتفاعلة والمواد الناتجة، وذلك لما تمتاز به المعادلة الكيميائية في أنها تعبير واضح الدلالة عن عدد الذرات أو الجزيئات المتفاعلة أو الناتجة في تفاعل كيميائي معين، فعلى سبيل المثال، يوضح التفاعل التالي:
</div>

A chemical equation can be used to calculate the quantities of reactants and products. This is because a chemical equation clearly expresses the number of atoms or molecules reacting or producing in a particular chemical reaction. For example, the following reaction:

$$2H_2SO_4 + Cu \rightarrow SO_2 + 2H_2O + CuSO_4$$

<div dir="rtl">

أن تفاعل ذرة نحاس واحدة مع جزيئين من حمض الكبريتيك يؤدي إلى تكون جزيء واحد من ثاني أكسيد الكبريت وجزيئين ماء وجزيء واحد من كبريتات النحاس. إلا أن قراءة المعادلة السابقة بالصورة المذكورة وعلى الرغم من صحتها هي قراءة غير محبذة؛ لأنه من المعلوم أنه من الناحية العملية لا يمكن التمكن من الحصول على ذرة نحاس واحدة وجزيئين من حمض الكبريت إضافة إلى إمكانية قراءتها بصورة صحيحة تمتاز عن الصورة السابقة بقربها من الواقع العملي، لذلك، من الأدق والأقرب إلى الواقع أن نعبّر عن التفاعل باستخدام المولات، فنقول: إن تفاعل (مول واحد) من ذرات النحاس مع (مولين) من جزيئات حمض الكبريت يؤدي إلى الحصول على (مول واحد) من جزيئات ثاني أكسيد الكبريت و(مولين) من جزيئات الماء و (مول واحد) من جزيئات كبريتات النحاس.
</div>

It shows that the reaction of one copper atom with two molecules of sulfuric acid produces one molecule of sulfur dioxide, two molecules of water, and one molecule of copper sulfate. However, reading the equation in this literal manner although technically correct is not preferable, because in practice it is impossible to obtain exactly one copper atom and two molecules of sulfuric acid.

A more appropriate and practically meaningful interpretation is to express the reaction in terms of moles, as follows: one mole of copper atoms reacts with two moles of sulfuric acid molecules to produce one mole of sulfur dioxide molecules, two moles of water molecules, and one mole of copper sulfate molecules.

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يدل المثال السابق على أن المعاملات في المعادلة الكيميائية إضافة إلى أنها تستخدم للدلالة على عدد الذرات أو الجزيئات فإنها يمكن أن تستخدم في نفس الوقت للدلالة على عدد المولات من الذرات أو الجزيئات الموجودة في المعادلة، ويمكن ترجمة ذلك في المثال السابق بالصورة التالية:
</div>

The preceding example indicates that the coefficients in a chemical equation, in addition to representing the number of atoms or molecules, can also be used to denote the number of moles of atoms or molecules involved in the reaction. This concept can be illustrated in the previous example as follows:

$2H_2SO_4$ + Cu → SO_2 + $2H_2O$ + $CuSO_4$

2 molecules H_2SO_4 + 1atom Cu →1molecule SO_2 +2molecules H_2O+1 molecule $CuSO_4$

2 mol H_2SO_4 + 1 mol Cu →1 mol SO_2 +2mole H_2O +1 mol $CuSO_4$

196 g H_2SO_4 + 63.5 g Cu → 64 g SO_2 + 36 g H_2O + 159.5 g $CuSO_4$

259.5 g Reactants → 259.5 g Products

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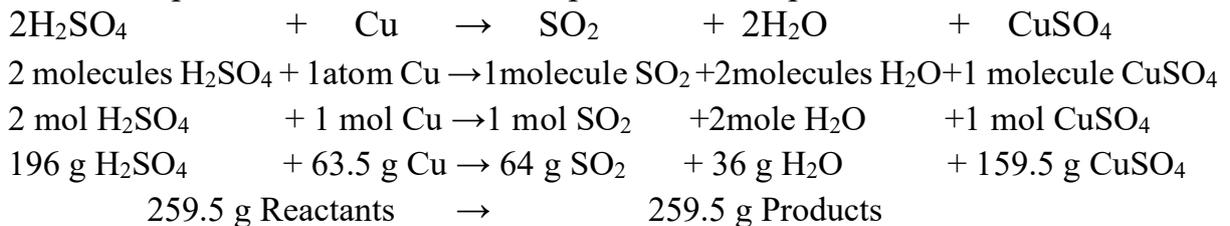
لاحظ أن المعادلة الكيميائية الموزونة تحقق قانون حفظ الكتلة.
</div>

Note that the balanced chemical equation satisfies the law of conservation of mass.

المعلومات التي يمكن الحصول عليها من المعادلة الكيميائية
Information That Can Be Obtained from a Chemical Equation

أولاً : معرفة حالة وطبيعة المواد المتفاعلة والناتجة:
في التفاعل التالي:

First: Determining the state and nature of the reactants and products:

For example, in the following reaction:

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$
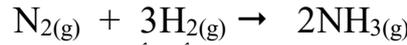
يرمز الحرف (g) إلى أن المادة في الحالة الغازية، أي أن هذا التفاعل يحدث بين غازي الهيدروجين والنيتروجين لتكوين غاز الأمونيا.

The symbol (g) indicates that the substance is in the gaseous state, meaning that the reaction results from the interaction of hydrogen gas with nitrogen gas to form ammonia gas.

ثانياً : تحديد النسبة بين أعداد الجزيئات:

Second: Determining the ratio between the numbers of molecules:

على سبيل المثال، يمكن ملاحظة النسب التالية من المعادلة السابقة:

For example, from the previous equation, we can observe the following ratios:

نسبة جزيئات N_2 إلى جزيئات H_2:

The ratio of N_2 molecules to H_2 molecules is:
$$\frac{1 \, molecule}{3 \, molecules}$$

نسبة جزيئات N_2 إلى جزيئات NH_3:

The ratio of N_2 molecules to NH_3 molecules is:
$$\frac{1 \, molecule}{2 \, molecules}$$

نسبة جزيئات H_2 إلى جزيئات NH_3:

The ratio of H_2 molecules to NH_3 molecules is:
$$\frac{3 \, molecules}{2 \, molecules}$$

ثالثاً : تحديد النسبة بين أعداد المولات:

Third: Determining the ratio between the numbers of moles:

نسبة عدد مولات N_2 إلى عدد مولات H_2:

The ratio of the number moles of N_2 to the number moles of H_2 is:
$$\frac{1 \, mol}{3 \, mol}$$

نسبة عدد مولات N_2 إلى عدد مولات NH_3:

The ratio of the number moles of N_2 to the number moles of NH_3 is:
$$\frac{1 \, mol}{2 \, mol}$$

نسبة عدد مولات H_2 إلى عدد مولات NH_3:

The ratio of the number moles of H_2 to the number moles of NH_3 is:
$$\frac{3 \, mol}{2 \, mol}$$

رابعاً: تحديد النسبة بين كتل المواد المتفاعلة والمواد الناتجة:

Fourth: Determine the ratio between the masses of the reactants and the products:

نسبة كتلة N_2 إلى كتلة H_2:

The ratio of the mass of N_2 to the mass of H_2 is:

$$\frac{28 \text{ g}}{6 \text{ g}}$$

نسبة كتلة N_2 إلى كتلة NH_3 :

The ratio of the mass of N_2 to the mass of NH_3 is:

$$\frac{28 \text{ g}}{34 \text{ g}}$$

نسبة كتلة H_2 إلى كتلة NH_3:

The ratio of the mass of H_2 to the mass of NH_3 is:

$$\frac{6 \text{ g}}{34 \text{ g}}$$

حسابات عدد المولات لمادة بمعلومية مولات مادة أخرى في المعادلة الكيميائية الموزونة

Calculating the number of moles of a substance given the moles of another substance in the balanced chemical equation

تُعدّ حسابات عدد المولات انطلاقًا من المعادلة الكيميائية الموزونة خطوةً أساسية لا غنى عنها في الكيمياء، وهي تمثّل جوهر ما يُعرف بـ القياسات الكميّة، وتكمن أهميتها في كونها الجسر الذي يربط بين العالم الدقيق غير المرئي للذرات والجزيئات، والعالم المادي الملموس الذي نتعامل معه في المختبرات والصناعة، حيث تُقاس المواد عادة بوحدات عملية مثل الجرام أو اللتر. ويمكن حساب عدد المولات باستخدام العلاقة التالية:

Calculating the number of moles from a balanced chemical equation is an essential step in chemistry. It represents the essence of what is known as stoichiometry. Stoichiometry is important because it serves as a bridge between the invisible, microscopic world of atoms and molecules and the tangible, physical world we encounter in laboratories and industry, where substances are usually measured in practical units such as grams or liters. The number of moles can be calculated using the following relationship:

$$\frac{\text{معامل المادة الأولى في المعادلة الموزونة}}{\text{معامل المادة الثانية في المعادلة الموزونة}} = \frac{\text{عدد مولات المادة الأولى}}{\text{عدد مولات المادة الثانية}}$$

$$\frac{\text{Coefficient of the first substance in the balanced equation}}{\text{Coefficient of the second substance in the balanced equation}} = \frac{\text{Number of moles the first substance}}{\text{Number of moles the second substance}}$$

يُعد المول الوحدة المحورية التي ترتكز عليها جميع الحسابات الكيميائية. وتوضح الخريطة المفاهيمية المرفقة (الشكل 4-1) كيف يمكن تحويل كمية المادة من وحدة المول إلى وحدات عملية أخرى مثل: الكتلة، والحجم، وعدد الجسيمات، وأنواع التراكيز المختلفة التي ستدرس لاحقا.

The mole is the central unit upon which all chemical calculations are based. The accompanying concept map (Figure 4-1) illustrates how the amount of a substance can be converted from the mole to other practical units such as mass, volume, number of particles, and the various types of concentrations that will be studied later.
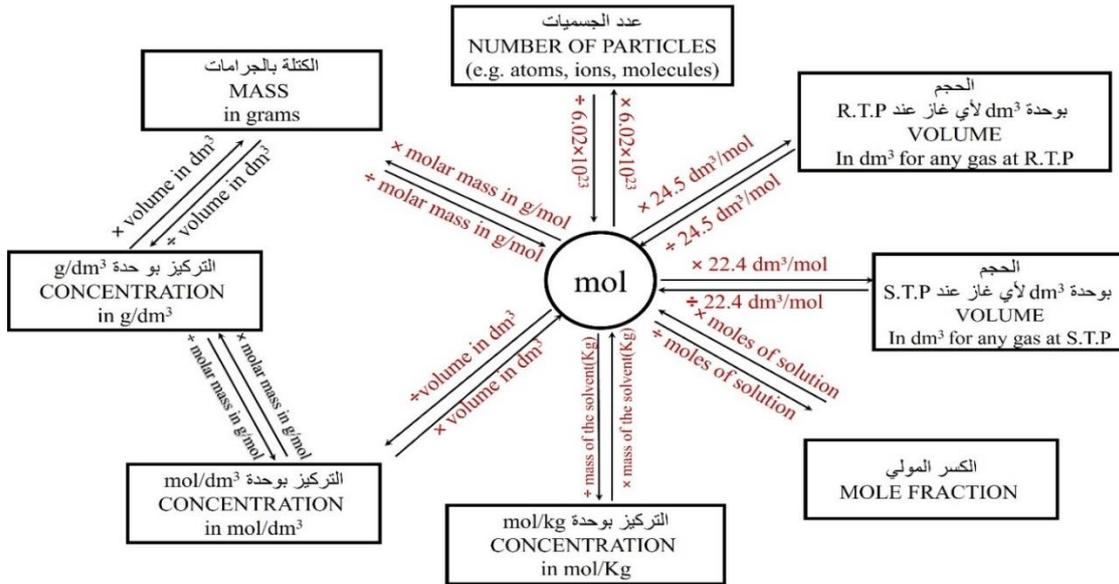
شكل 1-4: التحويل بين المول والوحدات الكيميائية الأخرى.

Figure 4-1: Converting between moles and other chemical units.

تدريب 4-1:   **Exercise 4-1:**

حسب معادلة تفاعل تحضير الأمونيا التالية أجب عن الأسئلة التالية.

According to the following reaction equation for the preparation of ammonia, answer the following questions.

$$N_2 + 3H_2 \rightarrow 2NH_3$$
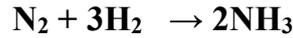
a. كم عدد مولات الأمونيا الناتجة من تفاعل 6.0 mol من الهيدروجين مع كمية كافية من النيتروجين؟

a. How many moles of ammonia are produced from the reaction of 6.0 mol of hydrogen with a sufficient amount of nitrogen?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

b. كم عدد مولات الهيدروجين اللازمة للتفاعل مع 252 g من النيتروجين؟

c. How many moles of hydrogen are required to react with 252 g of nitrogen?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

c. كم عدد جزيئات النيتروجين اللازمة لإنتاج 6.0 mol من الأمونيا؟

e. How many molecules of nitrogen are required to produce 6.0 mol of ammonia?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

d. ما كتلة الأمونيا الناتجة من تفاعل 0.450 kg من الهيدروجين مع كمية كافية من النيتروجين؟

f. What is the mass of ammonia produced by reacting 0.450 kg of hydrogen with a sufficient amount of nitrogen?

……………………………………………………………………………………………………
……………………………………………………………………………………………………

المادة المحددة للتفاعل   **Limiting Reactant**

يتوقف التفاعل الكيميائي عندما تُستهلك أيٌّ من المواد المتفاعلة تمامًا.

A chemical reaction stops when any of the reactants are completely used up.

نادرًا ما توجد المواد المتفاعلة في الطبيعة بالنسب التي تحددها معادلة التفاعل الموزونة.

Reactants rarely exist in nature in the proportions determined by a balanced reaction equation.

وعادة ما تكون إحدى المواد أو أكثر فائضة. ويستمر التفاعل إلى أن يتم استنفاد إحدى المواد أو جميعها. وينطبق هذا المبدأ على التفاعلات في المختبر؛ إذ تكون إحدى المواد أو أكثر فائضة، في حين تكون مادة واحدة محددة للتفاعل. لذا فإن كمية المواد الناتجة تعتمد على كمية المادة المحددة للتفاعل، **والمادة المحددة للتفاعل** هي المادة التي تستهلك كليًا في التفاعل وتحدد كمية المادة الناتجة.

Usually, one or more of the reactants are in excess. The reaction continues until one or all of the reactants are used up. This principle applies to reactions in the laboratory; one or more reactants are in excess, while one reactant is the limiting reactant. Therefore, the amount of products depends on the amount of the limiting reactant. The **limiting reactant** is the reactant that is completely consumed in the reaction and determines the amount of the product.

أما الكميات المتبقية من المواد المتفاعلة التي لم تُستهلك بعد توقف التفاعل فتُسمى **المواد الفائضة**. ولمساعدتك على فهم المواد المحددة للتفاعل والفائضة دعنا نأخذ المثال التالي عن عملية التجميع النهائي للسيارات:

The unreacted amounts of other reactants remaining after the reaction stops are called **excess reactants**. To help you understand limiting and excess reactants, let's consider the following example of the final assembly of a car:

التفاعل: 1سيارة ← 1 هيكل سيارة + 4 إطارات

Reaction: 4 tires + 1 car body → 1 car

إذا كان لدى مصنع سيارات **100 هيكل سيارة** و **240 إطاراً**، فإنّ عدد السيارات التي يمكن تجميعها هو 240/4=60، أي 60 سيارة كاملة.

If a car factory has 100 car bodies and 240 tires, the number of cars that can be assembled is $240 \div 4 = 60$ cars.

المادة المحددة للتفاعل: هي الإطارات؛ لأنها تحدد عدد السيارات الكاملة (60 سيارة).

The limiting reactant is the tires because they determine the number of complete cars that can be produced (60 cars).

المادة الفائضة: هي هياكل السيارات، حيث يتبقى منها: 40 = 60−100

Excess material: car bodies, of which: 100-60 = 40 remains

يمكن تعيين المادة المحددة للناتج من الخطوات:

The limiting reactant for a product can be determined using the following steps:

(1) احسب عدد المولات للمواد المتفاعلة.

(1) Calculate the number of moles of each reactant.

(2)اقسم عدد مولات كل مادة متفاعلة على معاملها في المعادلة الموزونة.

(2) Divide the number of moles of each reactant by its coefficient in the balanced equation

(a) إذا تساوت نواتج القسمة فإنّ جميع المتفاعلات تتفاعل كليا.

(a) If the quotients are equal, then all reactants react completely.

(b) المادة التي يكون ناتج قسمتها أقل هي التي تتفاعل كلياً (المادة المحددة للتفاعل).

(b) The substance that yields the smaller quotient is the one that reacts completely (the limiting reactant).

وهناك حالات خاصة يمكن معرفة المادة المحددة للتفاعل بمجرد النظر للمعادلة أو استخدام الطرق المبسّطة التالية:

In certain cases, the limiting reactant can be identified simply by inspecting the chemical equation or by applying the following simplified methods:

• إذا كانت معاملات المواد المتفاعلة متساوية وأعداد مولات المواد المتفاعلة متساوية، فإنّ كل المواد المتفاعلة تتفاعل كلياً.

• If the coefficients of the reactants are equal and the number of moles of the reactants are also equal, then all the reactants react completely.

توضيح: إذا مُزج 2 mol C مع 2 mol O$_2$ حسب المعادلة:

Explanation: If **2 mol of C** are mixed with **2 mol of O₂**, according to the equation:

$$C + O_2 \rightarrow CO_2$$
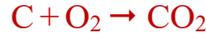
فإنّ جميع المواد المتفاعلة تتفاعل كلياً ولا يوجد فائض.

All the reactants, therefore, react completely, and no excess remains.

■ إذا كانت معاملات المواد المتفاعلة متساوية وأعداد مولات المواد المتفاعلة مختلفة، فإنّ المادة الأقل عدد مولات هي التي تتفاعل كلياً.

▪ If the coefficients of the reactants are equal but the numbers of moles of the reactants are different, the substance with the smaller number of moles is the one that reacts completely.

توضيح: إذا مُزج **3 mol C** مع **2 mol O₂** حسب المعادلة:

Explanation: If **3 mol of C** are mixed with **2 mol of O₂**, according to the equation:

$$C + O_2 \rightarrow CO_2$$
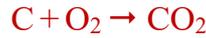
فإنّ الأكسجين (O₂) يتفاعل كلياً.

then oxygen (O_2) reacts completely.

■ إذا كانت معاملات المواد المتفاعلة مختلفة وأعداد مولات المواد المتفاعلة متساوية، فإن المادة الأعلى في قيمة المعامل هي التي تتفاعل كلياً.

▪ If the coefficients of the reactants are different while the number of moles of the reactants is the same, the substance with the larger coefficient is the one that reacts completely.

توضيح: إذا مُزج **4 mol H₂** مع **4 mol O₂** حسب المعادلة:

Explanation: If **4 mol of H₂** are mixed with **4 mol of O₂**, according to the equation:

$$2H_2 + O_2 \rightarrow 2H_2O$$

فإنّ الهيدروجين (H₂) يتفاعل كلياً.

then hydrogen (H_2) reacts completely.

Exercise 4-2: **تدريب 4-2:**

يَستعمل تفاعل البناء الضوئي في النباتات ثاني أكسيد الكربون والماء لإنتاج الجلوكوز C₆H₁₂O₆، وغاز الأكسجين.

Photosynthesis in plants uses carbon dioxide and water to produce the glucose $C_6H_{12}O_6$ and oxygen gas.

فإذا توفر لنبتة ما 88.0 g من ثاني أكسيد الكربون، و 64.0 g من الماء للقيام بعملية البناء الضوئي:

If a plant has 88.0 g of carbon dioxide and 64.0 g of water available for photosynthesis:

a. Write the balanced chemical equation for the reaction. ا. اكتب معادلة التفاعل الموزونة.

....

b. Identify the limiting reactant. b. حدد المادة المحددة للتفاعل.

....
....

c. Identify the excess reactant. c. حدد المادة الفائضة.

....
....

d. Calculate the mass of the excess reactant. d. احسب كتلة المادة الفائضة.

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e. Calculate the mass of the glucose produced e. احسب كتلة الجلوكوز الناتج.

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....

نسبة المردود المئوية / Percent Yield

نسبة المردود المئوية هي مقياس لمدى كفاءة التفاعل الكيميائي.

The percent yield is a measure of the efficiency of a chemical reaction.

افترض أنك تتدرب على الرماية الحرة في كرة السلة، وعليك القيام بمئة رمية. من الناحية النظرية يمكنك تحقيق مئة هدف، ولكن فعليًا قد لا تحقق هدفًا في كل رمية. وبالمثل للتفاعلات الكيميائية أيضا نواتج نظرية وأخرى فعلية.

Suppose you are practicing free throws in basketball and take one hundred shots. In theory, you could make all one hundred, but in practice, you might miss some. Similarly, chemical reactions have both theoretical and actual yields.

ما مقدار المادة الناتجة؟ / How much product?

في أثناء حل مسائل هذا الفصل، لا بد أنك قد استنتجت أن التفاعل الكيميائي يجرى في المختبر بناء على معادلة كيميائية موزونة، وتنتج عنه كمية من الناتج يتم حسابها مسبقًا.

While solving problems in this chapter, you may have concluded that a chemical reaction in the laboratory occurs according to a balanced chemical equation, producing a certain amount of product that can be calculated in advance.

لكن ذلك غير دقيق دائما، فكما أنه ليس من المحتمل أن تدخل كرة السلة الهدف 100 مرة من خلال 100 رمية خلال التدريب، كذلك لا تنتج معظم التفاعلات كمية الناتج المتوقعة.

But that's not always accurate, just as it is unlikely for a basketball to go through the hoop 100 times in 100 practice shots, most chemical reactions do not produce the expected amount of product.

ولأسباب متعددة، قد تتوقف التفاعلات قبل الاكتمال، فلا تنتج الكميات المتوقعة من النواتج. فقد تلتصق المواد المتفاعلة والناتجة ـ في الحالة السائلة ـ على أسطح الأوعية أو تتبخر، وفي بعض الحالات قد تنتج مواد أخرى غير متوقعة بسبب تفاعلات التنافس التي تقلل من كمية الناتج المرغوب فيه، أو قد تُترك بعض كميات المواد الصلبة جانبًا على ورقة الترشيح أو تُفقد بسبب عملية التنقية. ونتيجة هذه المشاكل، فإن الكيميائيين بحاجة إلى معرفة كيفية تحديد كمية الناتج في التفاعل الكيميائي.

For various reasons, reactions often stop before completion and fail to yield the anticipated amounts. Reactants and products—in the case of liquids—may stick to the surfaces of containers or evaporate. In some cases, unexpected substances may form due to competing reactions, reducing the amount of desired product. Some solid materials may remain on a filter paper or be lost during purification. Because of these issues, chemists need to know how to determine the actual amount of product in a chemical reaction.

المردود النظري والمردود الفعلي: / Theoretical Yield and Actual Yield:

في كثير من الحسابات السابقة، قمت بحساب كمية الناتج من كمية مادة متفاعلة معطاة. وتسمى كمية الناتج المحسوبة هذه المردود النظري للتفاعل، وهو أكبر كمية من الناتج يمكن الحصول عليها من كمية المادة المتفاعلة المعطاة.

In many of the previous calculations, you computed the amount of product from a given amount of reactant. This calculated amount of product is called the theoretical yield of the reaction, which is the maximum amount of product that can be obtained from the given amount of reactant.

نادرًا ما ينتج عن التفاعل الكيميائي مردود فعلي مطابق للمردود النظري المتوقع. يحدد الكيميائي المردود الفعلي للتفاعل من خلال تجربة دقيقة يحسب من خلالها كتلة المادة الناتجة. لذا، **فالمردود الفعلي** هو كمية المادة الناتجة عند إجراء التفاعل الكيميائي عمليًا.

It is rare for a chemical reaction to produce an actual yield that exactly matches the expected theoretical yield. Chemists determine the actual yield of a reaction through precise experiments, by measuring the mass of the product formed. Thus, **the actual yield** is the amount of product obtained when the chemical reaction is carried out practically.

نسبة المردود المئوية: يحتاج الكيميائيون إلى معرفة فاعلية التفاعل في إنتاج النواتج المرغوب فيها. ومن طرائق قياس فاعلية التفاعل حساب نسبة المردود المئوية. لذا، فإنّ **نسبة المردود المئوية** للنواتج هي نسبة المردود الفعلي إلى المردود النظري في صوره نسبة مئوية.

Percent Yield:

Chemists need to know the efficiency of a reaction in producing the desired products. One way to measure the efficiency of a reaction is by calculating the **percent yield**. Therefore, the percent yield of a product is the ratio of the actual yield to the theoretical yield, expressed as a percentage.

$$\text{نسبة المردود المئوية} \atop \text{Percent Yield} = \frac{\text{المردود الفعلي} \atop \text{Actual Yield}}{\text{المردود النظري} \atop \text{Theoretical Yield}} \times 100$$

Exercise 4-3:   **تدريب 4-3:**

يتكون الكلور من تفاعل حمض الهيدروكلوريك مع أكسيد المنجنيز وفقًا للمعادلة الموزونة الآتية:

Chlorine is produced by the reaction of hydrochloric acid with manganese dioxide according to the following balanced equation:

$$MnO_2 + 4HCl \rightarrow MnCl_2 + Cl_2 + 2H_2O$$

احسب المردود النظري ونسبة المردود المئوية للكلور إذا تفاعل g 96.9 من MnO_2 مع g 50.0 من HCl، وكان المردود الفعلي لـ Cl_2 هو g 20.0 .

Calculate the theoretical yield and the percent yield of chlorine if 96.9 g of MnO_2 reacts with 50.0 g of HCl, and the actual yield of Cl_2 is 20.0 g.

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تدريب 1-4:
Exercise 4-1:

a	4 mol NH_3
b	27 mol H_2
c	1.806×10^{24} molecules
d	2.55×10^3 g NH_3 = 2.55 kg

تدريب 2-4:
Exercise 4-2:

a	$6CO_{2(g)} + 6H_2O_{(l)} \rightarrow C_6H_{12}O_{6(aq)} + 6O_{2(g)}$
b	CO_2
c	H_2O
d	28.0 g H_2O
e	60.0 g $C_6H_{12}O_6$

تدريب 3-4:
Exercise 4-3:

Theoretical yield = 24.3 g Cl_2

Percent yield = 82.3 % Cl_2

5- الغازات Gases 05

نظرية الحركة الجزيئية The Kinetic-Molecular Theory

اقترح الكيميائيان بولتزمان وماكسويل - كل منهما على حدة - نموذجًا لتفسير خصائص الغازات. وقد عُرف هذا النموذج **بنظرية الحركة الجزيئية** التي تصف سلوك المادة بناءً على حركة جسيماتها. ولقد وضع هذا النموذج عدة افتراضات تتعلق بحجم جسيمات الغاز وحركتها وطاقتها، وتستند النظرية الحركية للغازات إلى الفرضيات الآتية:

The chemists Boltzmann and Maxwell, each independently, proposed a model to explain the properties of gases. This model is known as the kinetic molecular theory, which describes the behavior of matter based on the motion of its particles. This model makes several assumptions about the size, motion, and energy of gas particles. The kinetic theory of gases is based on the following assumptions:

1. تتكون الغازات من جسيمات ذات حجوم صغيرة جدًّا مقارنة بحجوم الفراغات التي تفصل بينها، كما أنها متباعدة، لذلك تنعدم قوى التجاذب والتنافر فيما بينها.

1. Gases consist of particles with very small volumes compared to the volume of the spaces separating them. They are also widely separated, so the forces of attraction and repulsion between them are absent.

2. جسيمات الغاز في حالة حركة مستمرة وعشوائية في الاتجاهات جميعها، وتصطدم بجسيمات أخرى أو بجدار الوعاء الذي توجد فيه، وتُعد التصادمات بين جسيمات الغاز مرنة. وفي التصادم المرن لا تُفقد الطاقة الحركية، ولكنها تنتقل بين الجسيمات المتصادمة.

2. Gas particles are in constant, random motion in all directions, colliding with other particles or with the walls of the container in which they are located. Collisions between gas particles are elastic. In elastic collisions, kinetic energy is not lost but is transferred between the colliding particles.

3. ينتج عن حركة الجسيمات طاقة حركية يحددها عاملان هما: كتلة الجسيم، وسرعته. ويمكن التعبير عن الطاقة الحركية للجسيم بالعلاقة الآتية:

3. The motion of particles produces kinetic energy, which is determined by two factors: the particle's mass and its speed. The kinetic energy of a particle can be expressed by the following relationship:

$$KE = \tfrac{1}{2}mv^2$$

حيث: KE = الطاقة الحركية، m = كتلة الجسيم، v = سرعة الجسيم المتجهة

Where: KE = kinetic energy, m = mass of the particle, v = velocity of the particle.

نجد أن جسيمات عينة من غاز ما لها الكتلة نفسها، إلاّ أنه ليس لها السرعة نفسها، لذلك تختلف كمية الطاقة الحركية لها. ولذا، تستخدم درجة الحرارة مقياسًا لمتوسط الطاقة الحركية لجسيمات المادة. فنجد أن أيّ غازين عند درجة الحرارة نفسها سوف يمتلكان متوسط الطاقة الحركية ذاته.

The particles in a sample of a gas have the same mass, but not the same speed, so their kinetic energy varies. Temperature is therefore used as a measure of the average kinetic energy of the particles of a substance. Any two gases at the same temperature will have the same average kinetic energy.

الخواص العامة للغازات General Properties of Gases

تتميز الغازات بعدد من الخواص، ومنها:

Gases have several properties, such as:

- **التمدد:**

لا تمتلك الغازات شكلًا أو حجمًا ثابتًا، لذلك هي تملأ شكل الوعاء الذي توضع فيه لأنها قادرة على التمدد.

- Expansion:

Gases have no definite shape or volume. They take the shape of their container because they can expand to fill any available space.

- **القابلية للانضغاط:**

جسيمات الغازات متباعدة وكثافتها منخفضة لذا فهي قابلة للانضغاط.

- ### Compressibility:

Because gas particles are widely spaced and have low density, gases are highly compressible.

والشكل 5-1 يوضح ما يحدث لكثافة الغاز الموجودة في الوعاء أثناء انضغاطه وتمدده.

Figure 5-1 shows what happens to the density of a gas in a container as it compresses and expands.
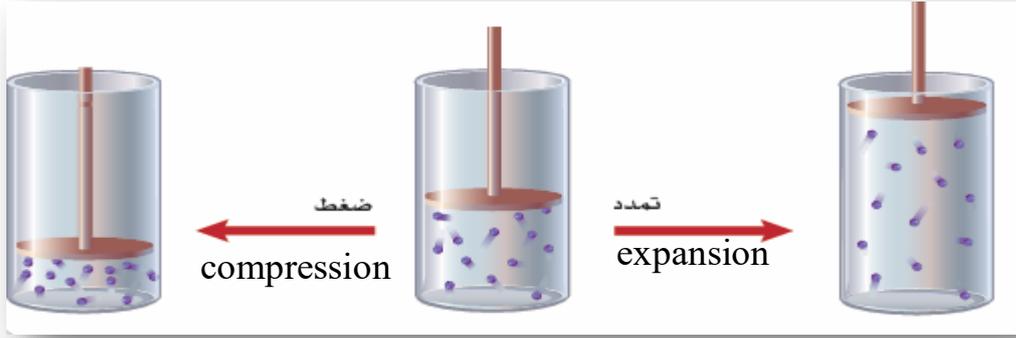
الشكل 5-1: إن تمدد الغاز وانضغاطه في وعاء مغلق يغير الحجم الذي تشغله كتلة ثابتة من الجسيمات.

Figure 5-1: The expansion and compression of a gas in a closed container change.

- **الميوعة:**

جسيمات الغازات تتحرك بحرية وسرعة في جميع الاتجاهات، مما يجعلها تنتشر بسهولة، ولهذا تُعد الغازات من الموائع.

- ### Fluidity:

Gas particles move freely and quickly in all directions, which makes them spread easily, and for this reason gases are considered fluids.

- **انخفاض الكثافة:**

جسيمات الغازات متباعدة عن بعضها وهذا ما يفسر انخفاض كثافتها، إلا أنه يمكن خفض كثافتها بشكل أكبر أو زيادتها بمجرد تغيير الحجم الذي يشغله الغاز بواسطة التحكم في الضغط مثلاً أو درجة الحرارة أو كلاهما.

- ### Low density:

Gas particles are far apart from each other, which explains their low density. However, their density can be decreased or increased simply by changing the volume the gas occupies—by adjusting the pressure, the temperature, or both.

- **القابلية للامتزاج:**

جميع الغازات قابلة للاختلاط والامتزاج مع بعضها البعض بشكلٍ تام لتكوين محلول متجانس، بغضّ النظر عن نوع الغاز، ويرجع ذلك إلى أن الجزيئات الغازية متباعدة جدًا وتتحرك بحرية عالية، مما يسمح لها بالامتزاج الكامل دون وجود حدود فاصلة بين المكونات.

- ### Miscibility:

All gases can mix completely with one another to form a homogeneous mixture, regardless of the type of gas. This occurs because gas molecules are very far apart and move freely, allowing complete mixing without any boundaries between components.

- **الانتشار والتدفق:**

وفقًا لنظرية الحركة الجزيئية، ونظرًا لأن المسافة كبيرة بين الجسيمات، فإن قوى التجاذب بين جسيمات الغاز تكاد تكون منعدمة. ولهذا تنتشر هذه الجسيمات بسهولة، ويكون المكان الذي ينتشر فيه الغاز في كثير من الأحيان

مشغولاً بغاز آخر، وتتسبب الحركة العشوائية لجسيمات الغازات باختلاط بعضها ببعض، حتى يصبح توزيع الغازات المختلطة متساويًا.

يصف <mark>الانتشار</mark> حركة تداخل المواد معًا، وقد يكون هذا المصطلح حديثًا، ولكن عملية الانتشار مألوفة لك. فأنت تشم رائحة الطعام عند طهيه في أرجاء المنزل كلها؛ بسبب انتشار جسيمات الغاز من منطقة ذات تركيز عالٍ (وهي في هذه الحالة المطبخ) إلى منطقة ذات تركيز منخفض (باقي أرجاء المنزل).

أما <mark>التدفق</mark> فهو عملية ذات صلة بالانتشار، ويحدث التدفق عندما يخرج الغاز من خلال ثقب صغير، كما هو موضح في الشكل 2-5.

■ Diffusion and Effusion:

According to the kinetic-molecular theory, there are no significant forces of attraction between gas particles. Thus, gas particles can flow easily past each other. Often, the space into which a gas flows is already occupied by another gas. The random motion of the gas particles causes the gases to mix until they are evenly distributed.

<mark>Diffusion</mark> is the term used to describe the movement of one material through another. The term might be new, but you are probably familiar with the process. If food is cooking in the kitchen, you can smell it throughout the house because the gas particles diffuse. Particles diffuse from an area of high concentration (the kitchen) to one of low concentration (the other rooms in the house).

<mark>Effusion</mark> is a process related to diffusion. During effusion, a gas escapes through a tiny opening, as shown in Figure 5-2.
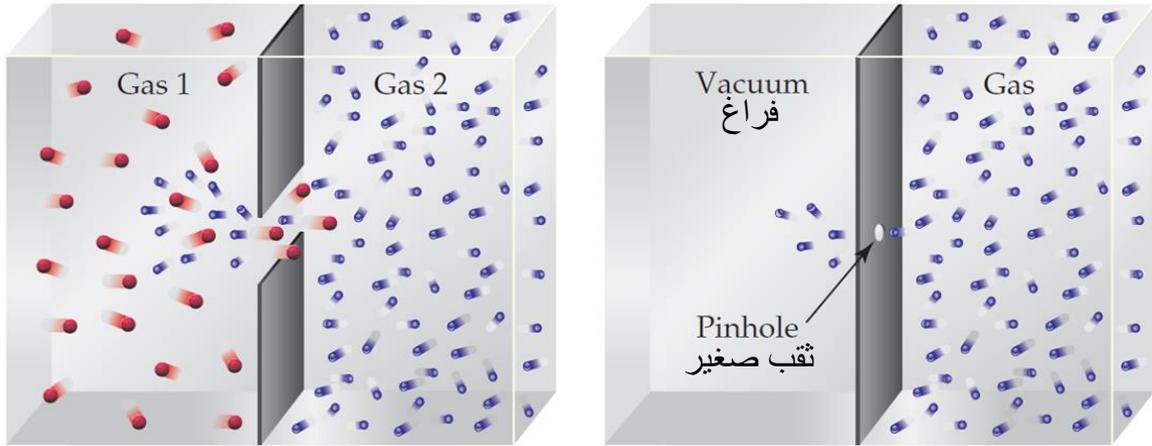
الانتشار Diffusion   التدفق Effusion

الشكل 2-5: الانتشار والتدفق

Figure 5-2: Diffusion and Effusion

من هذه الصفات يمكن لنا أن ندرك أن خواص الغازات ذات علاقة وثيقة بأربعة متغيرات هامة هي: الضغط، ودرجة الحرارة، والحجم، والكمية، وهذا ما سيتضح بشكل مفصل لاحقاً.

From these characteristics, we can realize that the properties of gases are closely related to four important variables: pressure, temperature, volume, and quantity, which will be explained in detail later.

Graham's Law	قانون جراهام

قام توماس جراهام بإجراء تجربة لقياس معدل سرعة تدفق غازات مختلفة عند درجة الحرارة نفسها، وقد صمم تجربته بحيث تتدفق الغازات إلى مكان لا توجد فيه مادة. وقد اكتشف وجود علاقة عكسية بين معدل سرعة التدفق والكتلة المولية للغاز.

Thomas Graham conducted an experiment to measure the rate of flow of different gases at the same temperature. He designed his experiment to flow the gases to a location

where there was no substance. He discovered an inverse relationship between the rate of flow and the molar mass of the gas.

قانون جراهام للتدفق ينص على أن معدل سرعة تدفق الغاز يتناسب عكسيًّا مع الجذر التربيعي للكتلة المولية.

Graham's Law of Effusion states that the rate of flow of a gas is inversely proportional to the square root of the molar mass.

تعتمد سرعة الانتشار بالدرجة الأولى على كتلة الجسيمات؛ حيث تنتشر الجسيمات الخفيفة أسرع من الثقيلة. ويمكن وصف متوسط الطاقة الحركية للغازات المختلفة عند درجة الحرارة نفسها بالمعادلة:

The rate of diffusion depends primarily on the mass of the particles; lighter particles diffuse faster than heavier particles. The average kinetic energy of different gases at the same temperature can be described by the equation:

$$KE = \tfrac{1}{2}mv^2$$

ومع ذلك فإن كتلة جسيمات الغاز تختلف من غاز إلى آخر. ولكي تمتلك الجسيمات الخفيفة متوسط الطاقة الحركية نفسه للجسيمات الثقيلة يجب أن تكون سرعتها المتجهة المتوسطة أكبر.

However, the mass of gas particles varies from one gas to another. For lighter particles to have the same average kinetic energy as heavier particles, their average velocity must be greater.

وينطبق قانون جراهام أيضًا على معدل الانتشار وهذا منطقي؛ إذ تنتشر الجسيمات الثقيلة أبطأ من الجسيمات الخفيفة عند درجة الحرارة نفسها. يمكنك باستخدام قانون جراهام كتابة نسبة رياضية للمقارنة بين معدل انتشار غازين.

Graham's law also applies to the rate of diffusion, which makes sense; heavier particles diffuse more slowly than lighter particles at the same temperature. Using Graham's law, you can write a mathematical ratio to compare the rates of diffusion of two gases:

$$\frac{Rate\ A}{Rate\ B} = \sqrt{\frac{M_B}{M_A}}$$

تدريب 5-1: اختر الإجابة الصحيحة فيما يلي:

Exercise 5-1: Choose the correct answer from the following:

1. يتسرب غاز بروميد الهيدروجين خلال فتحة صغيرة بمعدل 4 mL/s فما معدل تسرب غاز الميثان خلال نفس الفتحة؟

1. Hydrogen bromide gas leaks through a small opening at a rate of 4 mL/s. What is the rate of methane gas leaking through the same opening?

   a) 1.78 mL/s   b) 9 mL/s   c) 18 mL/s   d) 24 mL/s

2. غاز تبلغ سرعة انتشاره 1.414 مرة مقارنة بسرعة انتشار غاز ثاني أكسيد الكبريت احسب الكتلة المولية الغاز المجهول؟

2. A gas whose diffusion speed is 1.414 times that of sulfur dioxide. Calculate the molar mass of the unknown gas?

   a) 16 g/mol   b) 32 g/mol c) 64 g/mol   d) 128 g/mol

الضغط | Pressure

كما نعلم، أن الهواء يحتوي على ذرات وجزيئات غازية في حركة مستمرة. تصطدم هذه الجسيمات مع بعضها البعض ومع الأسطح المحيطة بها. كل تصادم يولّد قوة صغيرة، ولكن مجموع قوى جميع الجسيمات ينتج تأثيرًا كبيرًا.

As we know, air contains gas atoms and molecules in constant motion. These particles collide with each other and with surrounding surfaces. Each collision produces a very small force, but when the forces of all these particles are combined, they quickly add up to produce a large effect.

إن النتيجة المترتبة على التصادمات المستمرة بين ذرات أو جزيئات الغاز والأسطح المحيطة هي ما نُسميه الضغط، الذي بسببه يمكننا أن نشرب باستخدام الماصة، وأن ننفخ كرات السلة، وأن نتنفس. كما أن اختلاف الضغط في الغلاف الجوي للأرض هو ما يُولّد الرياح، في حين تساعدنا تغيرات الضغط على التنبؤ بحالة الطقس.

The result of the constant collisions between gas atoms or molecules and surrounding surfaces is what we call pressure. This pressure enables us to drink through a straw, inflate basketballs, and breathe. Pressure differences in Earth's atmosphere also generate wind, while pressure changes help us predict the weather.

أما الضغط (P) الذي يؤثر به الغاز فيُعرَّف بأنه القوة (F) الناتجة عن تصادم جسيمات الغاز مقسومة على مساحة السطح (A) الذي تصطدم به:

The pressure (P) exerted by a gas is defined as the force(F) resulting from the collision of the gas particles divided by the area (A) of the surface they collide with:

$$P = \frac{F}{A}$$

وبالتالي، يعتمد الضغط الذي تمارسه عينة غاز على عدد جسيمات الغاز في حجم معين، فكلما قلَّ عدد جسيمات الغاز، انخفضت القوة لكل وحدة مساحة وانخفض الضغط.

Therefore, the pressure exerted by a gas sample depends on the number of gas particles in a given volume, the fewer the gas particles, the lower the force per unit area, and the lower the pressure.

Measuring Atmospheric Pressure | قياس الضغط الجوي

يقاس الضغط الجوي بالبارومتر، وهو أنبوب زجاجي مفرغ من الهواء، يُغمر طرفه في حوض من الزئبق (Hg) كما هو موضح في الشكل 3-5. يدفع الضغط الجوي على سطح الزئبق السائل إلى الأعلى داخل الأنبوب المفرَّغ. ونظرا لكثافة الزئبق العالية (أكثر كثافة من الماء بـ 13.5 مرة)، فإن الضغط الجوي قادر على رفع عمود الزئبق إلى ارتفاع يقارب 0.760 m أو 760 mm . وبالمقابل، يمكن للضغط الجوي رفع عمود من الماء يصل ارتفاعه إلى حوالي 10.3 m. ولهذا السبب، يُعد عمود الزئبق وسيلة مناسبة وسهلة لقياس الضغط.

Atmospheric pressure is measured by a barometer. A barometer is an evacuated glass tube, the end of which is immersed in a pool of mercury (Hg) as shown in Figure 5-3. The atmospheric pressure on the surface of the liquid mercury pushes the mercury upwards inside the evacuated tube. Because mercury is very dense (13.5 times denser than water), atmospheric pressure supports a column of mercury about 0.760 m or 760 mm high. By contrast, atmospheric pressure supports a column of water about 10.3 m high. This makes a mercury column a convenient way to measure pressure.
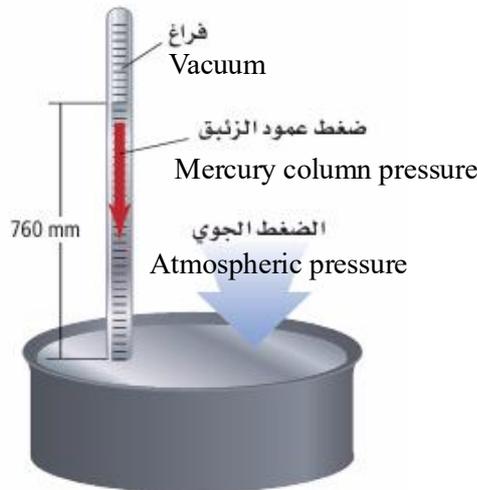
الشكل 3-5: البارومتر الزئبقي

Figure 5-3: Mercury barometer

ويحدّد ارتفاع الزئبق قوتين، إحداهما الجاذبية الأرضية المؤثرة في الزئبق بقوة ثابتة إلى أسفل، والأخرى القوة المعاكسة لها التي تدفع الزئبق إلى الأعلى، وتكون بفعل الهواء الضاغط على سطح الزئبق إلى أسفل. ويتغير ضغط الهواء بتغير درجة حرارة ورطوبة الجو.

The height of mercury is determined by two forces: gravity, which exerts a constant downward force on the mercury, and the opposing force, exerted by the air pressure on the mercury's surface, which pushes it upwards. Air pressure varies with changes in temperature and humidity.

<mark>المانومتر</mark> أداة تُستخدم لقياس ضغط الغاز المحصور، ويتكون من دورق متصل بأنبوب على شكل U مملوء بالزئبق كما هو موضح في الشكل 4-5.

A manometer is an instrument used to measure the pressure of a confined gas. It consists of a flask connected to a U-shaped tube filled with mercury, as shown in Figure 5-4.
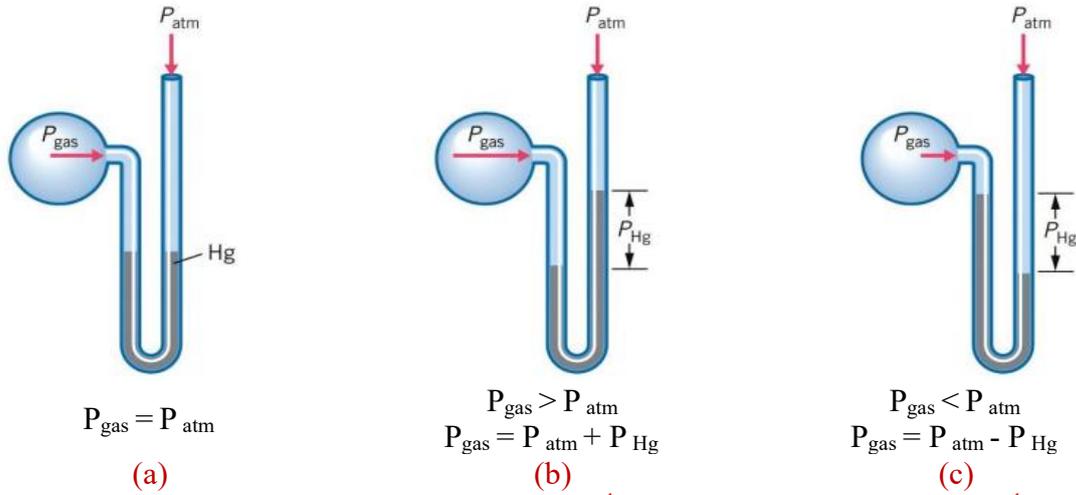
(a)
$P_{gas} = P_{atm}$
ضغط الغاز يساوي الضغط الجوي.
The gas pressure is equal to atmospheric pressure.

(b)
$P_{gas} > P_{atm}$
$P_{gas} = P_{atm} + P_{Hg}$
ضغط الغاز أكبر من الضغط الجوي.
The gas pressure is greater than atmospheric pressure.

(c)
$P_{gas} < P_{atm}$
$P_{gas} = P_{atm} - P_{Hg}$
ضغط الغاز أقل من الضغط الجوي.
The gas pressure is less than atmospheric pressure

الشكل 4-5: قياس ضغط الغاز باستخدام المانومتر مفتوح الطرف

Figure 5-4: Measuring gas pressure using an open-ended manometer

وحدات قياس الضغط إن وحدة قياس الضغط هي باسكال (Pa) . وقد اشتقت وحدة باسكال من وحدة قياس القوة العالمية نيوتن (N). وتساوي وحدة باسكال مقدار قوة واحد نيوتن لكل متر مربع (1Pa=1N/m^2). وما زالت مجالات كثيرة من العلوم تستخدم الوحدات التقليدية لقياس الضغط.

فعلى سبيل المثال، يسجل المهندسون الضغط على أنه عدد الأرطال لكل بوصة مربعة (psi) ، ويسجل الضغط المُقاس باستخدام البارومترات أو المانومترات بالملمترات الزئبقية (mmHg) وهناك وحدتان أخريان تعرف إحداهما تور (torr) والأخرى بار (bar).

Pressure Units: The unit of pressure is the pascal (Pa). The pascal is derived from the international unit of force, the newton (N). The pascal is equal to one newton per square meter (1Pa = 1N/m^2). Many fields of science still use traditional units of pressure. For example, engineers record pressure as pounds per square inch (psi), and pressure measured using barometers or manometers is recorded in millimeters of mercury (mmHg). Two other units are known as torr and bar.

التحويل بين وحدات الضغط
Converting between pressure units
1 atm = 76 cmHg = 760 mmHg =760 torr =1.01325 bar = 101325 Pa = 101.325 kPa

الغاز الحقيقي مقابل الغاز المثالي | **Real Versus Ideal Gases**

تتبع الغازات المثالية فرضيات نظرية الحركة الجزيئية التي درستها سابقًا. فحجم جسيمات الغاز المثالي يكاد يكون معدومًا، كما أن هذه الجسيمات لا تشغل حيزًا، ولا توجد قوى تجاذب أو تنافر بينها، ولا تتجاذب أو تتنافر مع جدران الوعاء الموجودة فيه. وتتحرك هذه الجسيمات حركة عشوائية دائمة في خطوط مستقيمة حتى يصطدم

بعضها ببعض أو بجدار الوعاء الذي يحتويها، وهذه التصادمات مرنة، مما يعني أن الطاقة الحركية للنظام لا تتغير، ويتبع الغاز المثالي قوانين الغاز تحت كل الظروف من الضغط ودرجة الحرارة.

Ideal gases follow the assumptions of the kinetic molecular theory you studied earlier. The particles of an ideal gas have almost no volume, occupy no space, and there are no forces of attraction or repulsion between them. They do not attract or repel each other with the walls of the container they are in. These particles move randomly in straight lines until they collide with each other or with the walls of the container they contain. These collisions are elastic, meaning the kinetic energy of the system does not change. An ideal gas follows the gas laws under all conditions of pressure and temperature.

ولكن في الحقيقة ليس هناك غاز مثالي؛ فجسيمات الغاز لها حجم وإن كان صغيرًا، وتوجد بينها قوى تجاذب، كما أن التصادمات فيما بينها وبين الوعاء ليست تصادمات مرنة تمامًا. وعلى الرغم من ذلك تسلك معظم الغازات سلوك الغاز المثالي في نطاقات واسعة من الضغط ودرجة الحرارة. كما أن الحسابات التي تجري باستخدام قانون الغاز المثالي تقارب القياسات التجريبية.

However, in reality, there is no such thing as an ideal gas. Gas particles have small volumes, but they do have attractive forces between them, and collisions between them and the container are not perfectly elastic. Nevertheless, most gases behave like an ideal gas over wide ranges of pressure and temperature. Calculations using the ideal gas law approximate experimental measurements.

متى يكون قانون الغاز المثالي غير مناسب للاستخدام مع الغاز الحقيقي؟ تحيد معظم الغازات الحقيقية في سلوكها عن الغاز المثالي عند الضغط العالي ودرجات الحرارة المنخفضة. فعلى سبيل المثال يسلك غاز النيتروجين سلوك الغاز الحقيقي وعند انخفاض درجات حرارة غاز النيتروجين تنخفض طاقة جسيماته الحركية، وهذا يعني أن قوى التجاذب بين هذه الجسيمات قوية، مما يجعلها تؤثر في سلوكها. وعندما تنخفض درجة الحرارة بقدر كاف يتكاثف الغاز الحقيقي مكوّنًا سائلاً. ويسلك غاز البروبان أيضًا سلوكَ الغاز الحقيقي. وتعمل زيادة الضغط على الغاز على إجبار جسيماته على الاقتراب بعضها من بعض، حتى يصبح من غير الممكن إهمال الحجم الذي تشغله الجسيمات، وتتحول الغازات الحقيقية - ومنها البروبان - إلى سائل إذا تعرضت لضغط كافي.

When is the ideal gas law not suitable for use with real gases? Most real gases deviate from the ideal gas behavior at high pressure and low temperature. For example, Nitrogen gas behaves like a real gas. As the temperature of nitrogen gas decreases, the kinetic energy of its particles decreases. This means that the attractive forces between these particles are strong, affecting their behavior. When the temperature drops sufficiently, the real gas condenses into a liquid. Propane also behaves like a real gas. Increasing the pressure on the gas forces its particles closer together, until the volume occupied by the particles becomes negligible. Real gases, including propane, turn into a liquid if subjected to sufficient pressure.

تؤثر طبيعة الجسيمات التي يتكوّن منها الغاز في سلوكه بطريقة مثالية. فمثلا يوجد بين جسيمات الغاز القطبية كما في بخار الماء قوى تجاذب أكبر من القوى التي تكون بين جسيمات الغازات غير القطبية كالهيليوم. فتنجذب الأطراف المختلفة للجسيمات القطبية بعضها نحو بعض بقوى تجاذب كهروستاتيكية، كما في الشكل 5-5، لذا لا تسلك الغازات القطبية سلوك الغاز المثالي. وتشغل جسيمات الغازات غير القطبية الكبيرة الحجم كالبيوتان (C_4H_{10}) حيزًا أكبر من الحيز الذي يشغله عدد مماثل من جسيمات غاز صغيرة الحجم كالهيليوم (He). ولهذا السبب تميل جسيمات الغاز الكبيرة إلى الابتعاد عن السلوك المثالي أكثر من جسيمات الغاز الصغيرة.

The nature of the particles that make up a gas influences its behavior in an ideal way. For example, the attractive forces between the particles of polar gases, such as water vapor, are stronger than those between the particles of nonpolar gases, such as helium. The opposite ends of the polar particles are attracted to each other by electrostatic forces, as shown in Figure 5-5. Therefore, polar gases do not behave like an ideal gas. Large, nonpolar gas particles, such as butane (C_4H_{10}), occupy more space than an equal number of small gas

The Gas Laws | قوانين الغازات

في هذا القسم، سنستعرض عدداً من القوانين الرياضية التي تربط بين خصائص الغازات. تستند هذه القوانين إلى تجارب أجريت بعناية لقياس خصائص الغازات ذات الصلة، ومن خلال نتائج هذه التجارب، يمكن اكتشاف العلاقات الرياضية بين تلك الخصائص، وغالباً ما تُعرض هذه العلاقات بطريقة تصويرية باستخدام الرسوم البيانية (المنحنيات).

In this section we will consider several mathematical laws that relate the properties of gases. These laws derive from experiments involving careful measurements of the relevant gas properties. From these experimental results, the mathematical relationships among the properties can be discovered. These relationships are often represented pictorially by means of graphs (plots).

Boyle's law | قانون بويل

أجرى الكيميائي الأيرلندي روبرت بويل أولى التجارب الكمية على الغازات. باستخدام أنبوب على شكل حرف J مغلق من أحد طرفيه (الشكل 5-5).

Irish chemist Robert Boyle conducted the first quantitative experiments on gases using a J-shaped tube closed at one end (Figure 5-5).
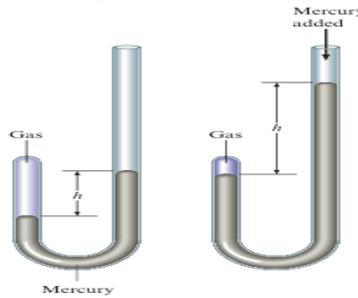
الشكل 5-5: أنبوب على شكل حرف J، مشابه لأنبوب بويل. عند إضافة الزئبق إلى الأنبوب، يزداد الضغط على الغاز المحصور، مما يؤدي إلى انخفاض حجمه.

Figure 5-5: A J-tube similar to the one used by Boyle. When mercury is added to the tube, pressure on the trapped gas is increased, resulting in a decreased volume.

درس بويل العلاقة بين ضغط الغاز المحصور وحجمه. ووجد أن حاصل ضرب الضغط في الحجم لعينة الهواء المحصور ثابتة.

Boyle studied the relationship between the pressure of a confined gas and its volume, and found that the product of pressure and volume for a confined sample of air is constant

يمكن تمثيل هذا السلوك بالمعادلة:

This behavior can be represented by the equation:

$$PV = k$$

وهو ما يُسمى قانون بويل، حيث k ثابت لعينة مُعينة من الهواء عند درجة حرارة مُحددة.

This is called Boyle's Law, where k is a constant for a given sample of air at a given temperature.

يمكن تمثيل قانون بويل باستخدام رسمين بيانيين مُختلفين. يُشكل النوع الأول من الرسم البياني، P مقابل V، منحنى يُسمى القطع الزائد (الشكل 5-6). بالنظر إلى هذا الرسم البياني لاحظ أنه مع انخفاض الضغط بمقدار النصف تقريبًا (من 58.8 إلى 29.1)، يتضاعف الحجم (من 24.0 إلى 48.0). بعبارة أخرى، هناك علاقة عكسية بين الضغط والحجم.

Boyle's law can be represented using two different graphs. The first type of graph, P versus V, forms a curve called a hyperbola (Figure 5-6). Looking at this graph, note that as the

pressure decreases by about half (from 58.8 to 29.1), the volume doubles (from 24.0 to 48.0). In other words, there is an inverse relationship between pressure and volume.

ينص **قانون بويل** على أن حجم (V) كمية محددة من الغاز يتناسب عكسيا مع الضغط (P) الواقع عليه عند ثبوت درجة حرارته.

Boyle's Law states that the volume (V) of a given quantity of gas is inversely proportional to the pressure (P) exerted on it at a constant temperature.

يُمكن الحصول على النوع الثاني من الرسم البياني بإعادة ترتيب قانون بويل للحصول على:

The second type of graph can be obtained by rearranging Boyle's Law to get:

$$V = \frac{k}{P} = k\frac{1}{P}$$

وهي معادلة الخط المستقيم من النوع:

It is the equation of a straight line of the type:

$$y = mx + b$$

حيث يمثل m الميل، و b نقطة تقاطع الخط المستقيم. في هذه الحالة، $y = V$، و $x = 1/P$، و $m = k$، و $b = 0$. وبالتالي فإن رسم V مقابل $1/P$ باستخدام بيانات بويل يُعطي خطًا مستقيمًا نقطة تقاطعه صفر كما في (الشكل 7-5).

where m represents the slope, and b represents the intercept of the line. In this case, $y = V, x = 1/P, m = k$, and $b = 0$. Thus, plotting V versus 1/P using Boyle's data gives a straight line with a zero intercept as in (Figure 5-7).
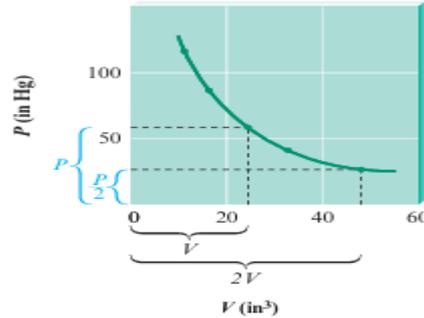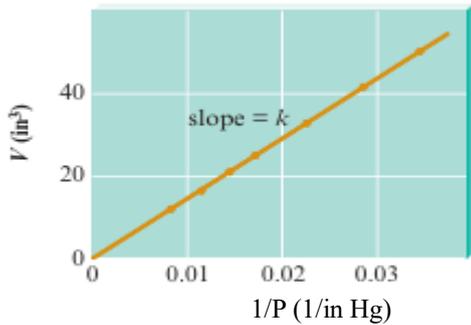
الشكل 7-5: يُعطي الرسم البياني لـ V مقابل 1/P خطًا مستقيمًا. ميل هذا الخط يساوي قيمة الثابت k.

Figure 5-7: A plot of V versus 1/P gives a straight line. The slope of this line equals the value of the constant k.

الشكل 6-5: يُظهر الرسم البياني لـ P مقابل V أن الحجم يتضاعف مع انخفاض الضغط إلى النصف.

Figure 5-6: A plot of P versus V shows that the volume doubles as the pressure is halved.

وعلى الرغم من أن القيم المنفردة لكل من الضغط والحجم تتغير بشكل كبير بثبوت درجة الحرارة وبقاء كمية الغاز ثابتة، لكن حاصل الضرب P في V يساوي دائما كمية ثابتة؛ لذا فإنه لعينة من غاز تحت ظرفين مختلفين بثبوت درجة الحرارة، يكون:

Although the individual values of pressure and volume change significantly at constant temperature and constant gas volume, the product of P and V always equals a constant quantity. Therefore, for a sample of gas under two different conditions at constant temperature, it is:

$$P_1V_1 = k$$
$$P_2V_2 = k$$

لذا يمكن التعبير عن قانون بويل رياضيا على النحو الآتي:

Therefore, Boyle's law can be expressed mathematically as follows:

$$P_1V_1 = P_2V_2$$

يبين الشكل 8-5 العلاقة العكسية بين الضغط والحجم.

Figure 5-8 shows the inverse relationship between pressure and volume.

P_1V_1 = (1 atm)(10 L)
= 10 atm · L
= ثابت

P_2V_2 = (2 atm)(5 L)
= 10 atm · L
= ثابت

P_3V_3 = (4 atm)(2.5 L)
= 10 atm · L
= ثابت
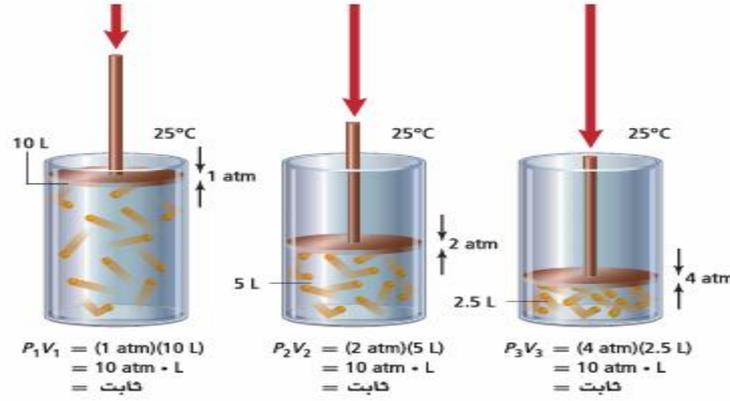
الشكل 8-5: عندما يزيد الضغط الخارجي على مكبس الأسطوانة يقل حجم الغاز داخل الأسطوانة.

Figure 5-8: When the external pressure on the piston of the cylinder increases, the volume of the gas inside the cylinder decreases.

تدريب 2-5:

عينة من غاز مثالي مجهول الحجم وضع في دورق له صمام وتحت ضغط جوي واحد، عند فتح الصمام سمح للغاز بالتمدد داخل دورق فارغ حجمه 0.5 L موصول بالدورق الأول بوصله مهملة الحجم، وُجد أن درجة الحرارة ثابتة وأصبح الضغط 532 mmHg، احسب حجم الدورق الأول؟

Exercise 5-2:

A sample of an ideal gas of unknown volume was placed in a flask with a valve and under one atmosphere of pressure. When the valve was opened, the gas was allowed to expand into an empty flask with a volume of 0.5 L connected to the first flask by a non-volume connector. The temperature was found to be constant and the pressure became 532 mmHg. Calculate the volume of the first flask?

....

....

قانون شارل | Charles's Law

درس العالم شارل العلاقة بين حجم الغاز ودرجة حرارته، حيث لاحظ أن حجم الغاز يزداد بزيادة درجة الحرارة عند ثبوت كمية الغاز والضغط. توضح الأسطوانات في الشكل 9-5 كيفية تغير حجم كمية محددة من الغاز بتسخينه.

The scientist Charles studied the relationship between gas volume and temperature, noting that gas volume increases with increasing temperature when the gas quantity and pressure are constant. The cylinders in Figure 5-9 illustrate how the volume of a specific amount of gas changes when it is heated.

$\dfrac{V_1}{T_1}$ = $\dfrac{300 \text{ mL}}{150 \text{ K}}$
= 2 mL/K
= ثابت

$\dfrac{V_2}{T_2}$ = $\dfrac{600 \text{ mL}}{300 \text{ K}}$
= 2 mL/K
= ثابت
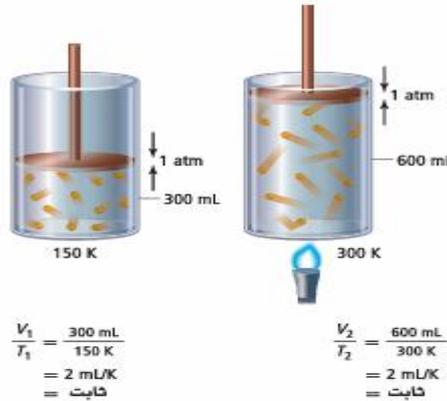
الشكل 9-5: عند تسخين الأسطوانة تزداد الطاقة الحركية لجسيمات الغاز، فتدفع المكبس للأعلى

Figure 5-9: When the cylinder is heated, the kinetic energy of the gas particles increases, pushing the piston upward

ينص **قانون شارل** على أن حجم (V) كمية محددة من الغاز يتناسب طرديا مع درجة حرارته بالكلفن (T) عند ثبوت الضغط، ويلاحظ من الشكل 10-5 العلاقة الطردية والتناسب المباشر بين الحجم ودرجة الحرارة بالكلفن.

Charles's law states that the volume (V) of a given quantity of gas is directly proportional to its temperature in Kelvin (T) at constant pressure. Figure 5-10 shows the direct relationship between volume and temperature in Kelvin.

شكل 10-5: العلاقة بين الحجم ودرجة الحرارة بالكلفن.
Figure 5-10: The relationship between volume and temperature in Kelvin.

يمكن التعبير عن قانون شارل بالعلاقة الرياضية التالية:

Charles's law can be expressed by the following mathematical relationship:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

تدريب 5-3:
Exercise 5-3:

يشغل غاز حجما مقداره 0.67 L عند درجة حرارة 350 K . ما درجة الحرارة اللازمة لخفض الحجم بمقدار 45%؟

A gas occupies a volume of 0.67 L at a temperature of 350 K. What temperature is required to reduce the volume by 45%?

....

....

Gay-Lussac's law   قانون جاي- لوساك

ينتج الضغط عن اصطدام جسيمات الغاز بجدران الوعاء؛ فكلما ارتفعت درجة الحرارة زاد عدد الاصطدامات وطاقتها؛ لذا تؤدي زيادة درجة الحرارة إلى زيادة الضغط إذا لم يتغير الحجم.

Pressure results from the collision of gas particles with the walls of the container. The higher the temperature, the greater the number and energy of collisions. Therefore, increasing temperature leads to an increase in pressure if the volume remains unchanged.

وقد وجد جاي لوساك أن درجة الحرارة المطلقة تتناسب طرديًا مع الضغط، كما هو موضح في الشكل 11-5.

Gay-Lussac found that absolute temperature is directly proportional to pressure, as shown in Figure 5-11.
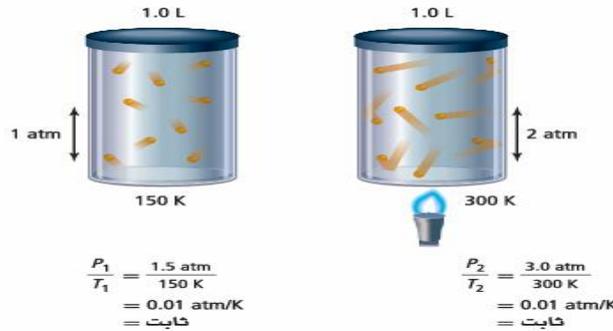
الشكل 11-5: عند تسخين الأسطوانة تزداد الطاقة الحركية لجسيمات الغاز، مما يؤدي إلى زيادة اصطداماتها بجدار الإناء، ولأن حجم الأسطوانة ثابت يزداد ضغط الغاز.

Figure 5-11: When the cylinder is heated, the kinetic energy of the gas particles increases, leading to an increase in their collisions with the vessel wall. Because the volume of the cylinder is constant, the gas pressure increases.

وينص **قانون جاي لوساك** على أن ضغط (P) مقدار محدّد من الغاز يتناسب طرديًّا مع درجة الحرارة بالكلفن(T) له، عند ثبوت الحجم. ويلاحظ من الشكل12-5 العلاقة الطردية والتناسب المباشر بين الضغط ودرجة الحرارة بالكلفن.

Gay-Lussac's law states that the pressure (P) of a given volume of gas is directly proportional to its temperature in Kelvin (T), given constant volume. Figure 5-12 shows the direct and proportional relationship between pressure and temperature in Kelvin.

الشكل 5-12: العلاقة بين الضغط ودرجة الحرارة بالكلفن.
Figure 5-12: The relationship between pressure and temperature in Kelvin.

يمكن التعبير عن قانون جاي ـ لوساك بالعلاقة الرياضية التالية:
Gay-Lussac's law can be expressed mathematically as follows:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

تدريب 5-4:

إذا كان ضغط عينة من الغاز يساوي 30.7 kPa عند درجة حرارة0.00°C، فكم ينبغي أن ترتفع درجة الحرارة السيليزية للعينة حتى يتضاعف ضغطها؟ عند ثبوت الحجم.

Exercise 5-4:
If the pressure of a sample of gas is 30.7 kPa at a temperature of 0.00°C, how much higher in Celsius must the temperature of the sample be for its pressure to double? At constant volume.

....
....

The Combined Gas Law	القانون العام للغازات

يمكن أن يتغير كل من الضغط ودرجة الحرارة والحجم في العديد من التطبيقات العملية للغازات، كما يمكن دمج قانون بويل وقانون شارل وقانون جاي- لوساك في قانون واحد يطلق عليه **القانون العام للغازات**، وهو يحدّد العلاقة بين الضغط ودرجة الحرارة والحجم لكمية محدّدة من الغاز. ويوجد بين المتغيرات الثلاثة نفس العلاقة الموجودة في القوانين الأخرى. فالضغط يتناسب عكسيًّا مع الحجم، وطرديًّا مع درجة الحرارة.

Pressure, temperature, and volume can all change in many practical applications of gases. Boyle's Law, Charles's Law, and Gay-Lussac's Law can be combined into a single law called the **Combined gas law**, which defines the relationship between pressure, temperature, and volume for a given quantity of gas. The three variables share the same relationship as in the other laws. Pressure is inversely proportional to volume and directly proportional to temperature.

ويمكن التعبير عن القانون العام للغازات رياضيًّا على النحو الآتي:
The Combined gas law can be expressed mathematically as follows:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

يساعدك القانون العام للغازات على حل المسائل التي تتضمن أكثر من متغير واحد، كما يقدم لك طريقة لتذكر القوانين الثلاثة الأخرى دون ستذكر معادلاتها، يمكننا القانون العام للغازات من اشتقاق القوانين الأخرى من خلال تذكر المتغير الثابت في كل حالة.

The Combined gas law helps you solve problems involving more than one variable. It also provides a way to remember the other three laws without remembering their equations. The Combined gas law allows us to derive the other laws by remembering the constant variable in each case.

تدريب 5-5:

ما درجة الحرارة اللازمة لكي يتضاعف ضغط عينة من غاز النيون إذا انخفض الحجم الأصلي للغاز عند 40°C- إلى الربع.

Exercise 5-5:

What temperature is needed for the pressure of a sample of neon gas to double if the original volume of the gas at -40°C was reduced to a quarter?
a) 116.5 °C   b) -20 °C c) -156.5°C   d) 389.5 °C

قانون أفوجادرو | **Avogadro's Law**

يوضح الشكل 5-13 حجم عينة غاز (عند ثبوت درجة حرارة والضغط) كدالة لكمية الغاز (بالمول) في العينة. يمكننا أن نرى أن العلاقة الخطية بين الحجم والكمية.

Figure 5-13 shows the volume of a gas sample (at constant temperature and pressure) as a function of the amount of gas (in moles) in the sample. We can see that the relationship between volume and amount is linear.
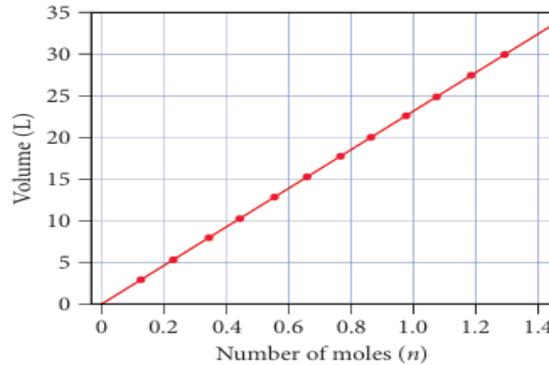
الشكل 5-13: العلاقة بين الحجم وعدد المولات.

Figure 5-13: Relationship between volume and number of moles.

اقترح **أفوجادرو فرضية** تنص على أنه عند ثبوت كل من الضغط ودرجة الحرارة فإن الحجوم المتساوية من الغازات تمتلك العدد نفسه من الجزيئات (أو العدد نفسه من الذرات في حالة الغازات أحادية الذرة). ويتبع ذلك أن حجم (V) غاز معين يجب أن يتناسب طرديًا مع عدد مولات جزيئات الغاز الموجودة (n).

Avogadro proposed that, at constant pressure and temperature, equal volumes of gases contain the same number of molecules (or the same number of atoms in the case of monatomic gases). It follows that the volume (V) of a given gas must be directly proportional to the number of moles of gas molecules present (n)

ويمكن التعبير عن قانون أفوجادرو رياضيًا على النحو الآتي:

Avogadro's law can be expressed mathematically as follows:

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

وحسب قانون أفوجادرو، نرى أنه عند تفاعل غازين مع بعضهما، فإن النسبة تكون بينهما بسيطة. وعندما يكون الناتج غازاً يرتبط حجمه مع حجوم المواد المتفاعلة بنسب بسيطة أيضا.

According to Avogadro's law, when two gases react with each other, they are in a simple ratio. When the product is a gas, its volume is also related to the volumes of the reactants in simple ratios.

For وعلى سبيل المثال، لنفترض تحضير الأمونيا من تفاعل جزيئات الهيدروجين مع جزيئات النيتروجين:
example, suppose ammonia is prepared from the reaction of hydrogen molecules with nitrogen molecules:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$
$$\text{3 mol} \quad \text{1 mol} \quad \text{2 mol}$$
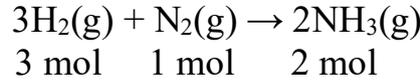
ولأنه عند ثبوت درجة الحرارة والضغط، تتناسب حجوم الغازات طرديًا مع عدد مولات الغازات الموجودة. يمكننا الآن كتابة:

Because at constant temperature and pressure, the volumes of gases are directly proportional to the number of moles of gases present. We can now write:

$$3H_2(g) \quad + \quad N_2(g) \quad \rightarrow \quad 2NH_3(g)$$
$$\text{3 volume} \quad \text{1volume} \quad \text{2 volume}$$
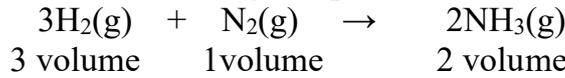
نسبة حجم الهيدروجين إلى النيتروجين هي 3:1، ونسبة الأمونيا (الناتج) إلى الهيدروجين والنيتروجين المتحدة (المتفاعلات) هي: 4:2 أو 2:1 كما هو موضح في الشكل 14-5.

The ratio of the volume of hydrogen to nitrogen is 3:1, and the ratio of ammonia (the product) to combined hydrogen and nitrogen (the reactants) is 2:4, or 1:2, as shown in Figure 5-14.
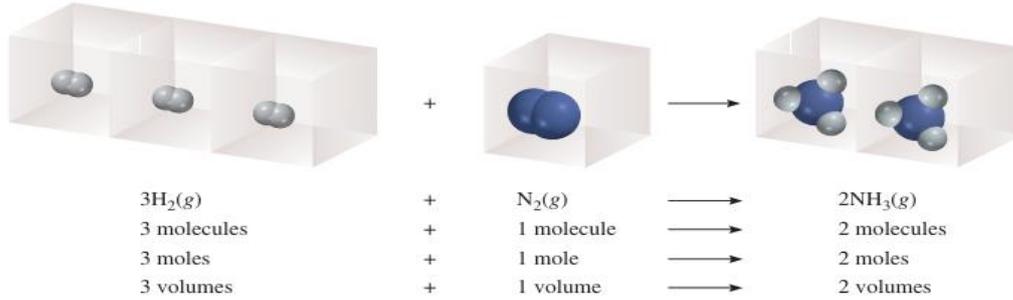
الشكل 5-14: العلاقة بين حجم الغازات في التفاعل الكيميائي.
Figure 5-14: The relationship between the volume of gases in a chemical reaction.

The Ideal Gas Law | قانون الغاز المثالي

Let's summarize the gas laws we've learned: | دعنا نلخص قوانين الغازات التي تعرفنا عليها:

Boyle's Law: When n and T are constant | قانون بويل: عند ثبوت n وT

$$V \propto \frac{1}{P}$$

Charles' Law: When n and P are constant | قانون شارل: عند ثبوت n وP

$$V \propto T$$

Avogadro's Law: When P and T are constant | قانون أفوجادرو: عند ثبوت P وT

$$V \propto n$$

يمكننا دمج هذه التعابير لنحصل على معادلة رئيسة تصف سلوك الغازات:

We can combine all three expressions to form a single master equation for the behavior of gases:

$$V \propto \frac{nT}{P}$$
$$V = R \frac{nT}{P}$$
$$PV = nRT$$

حيث R هو ثابت التناسب، ويدعى ثابت الغاز. وتسمى المعادلة السابقة بمعادلة الغاز المثالي التي تصف العلاقة بين المتغيرات الأربعة: P و V و T و n . ويبين الجدول التالي القيم الرقمية لـ R بوحدات مختلفة للضغط:

where R is a constant of proportionality, also called the gas constant. The previous equation is called the ideal gas equation, which describes the relationship between the four variables: P, V, T, and n. The following table shows the numerical values of R in different pressure units:

وحدات R R- units	قيمة R R-value
$\dfrac{L.atm}{mol.K}$	0.0821
$\dfrac{L.kPa}{mol.K}$	8.314
$\dfrac{L.mmHg}{mol.K}$	62.4

لاحظ أن قانون الغاز المثالي يحتوي على قوانين الغاز البسيطة التي تم مناقشتها كما موضح في الشكل التالي:

Note that the ideal gas law contains the simple gas laws discussed as shown in the following figure:

$$PV = nRT$$

constant n and T	constant n and P	constant P and T
$V = \dfrac{nRT}{P}$	$V = \dfrac{nRT}{P}$	$V = \dfrac{nRT}{P}$
$V \propto \dfrac{1}{P}$	$V \propto T$	$V \propto n$
Boyle's Law	Charles's Law	Avogadro's Law
قانون بويل	قانون شارل	قانون أفوجادرو
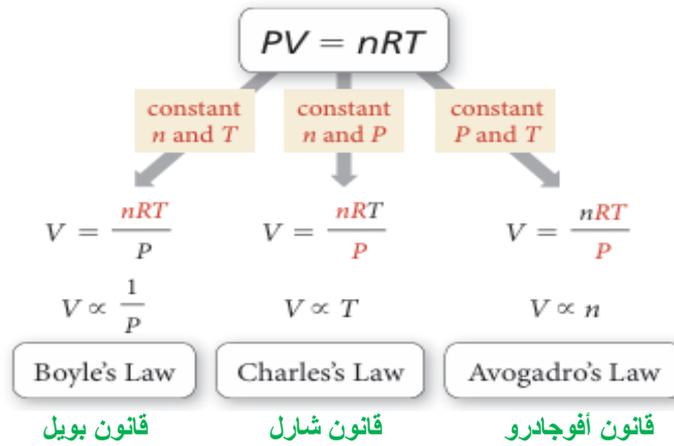
تدريب 5-6:

غازان A و B محصوران في وعاء حجمه لتر واحد عند درجة حرارة 70.0°C وضغط كلي 6.0 atm فإذا كان عدد مولات الغاز A ضعف عدد مولات الغاز B فاحسب:

a. عدد مولات كل من الغازين A و B.

b. الضغط الجزئي لكل غاز من الغازين في الخليط.

Exercise 5-6:

Two gases A and B are confined in a container with a volume of one liter at a temperature of 70.0°C and a total pressure of 6.0 atm. If the number of moles of gas A is twice the number of moles of gas B, calculate:

a. The number of moles of gases A and B.

b. The partial pressure of each of the two gases in the mixture.

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The Ideal Gas Law - Molar Mass and Density   قانون الغاز المثالي ـ الكتلة المولية والكثافة

يمكن أن يستخدم قانون الغاز المثالي في إيجاد أي من قيم المتغيرات الأربعة P و V و T و *n* ، إذا كانت القيم الثلاث الأخرى معروفة. كما يمكن إعادة ترتيب المعادلة PV = nRT لحساب الكتلة المولية والكثافة لعينة من الغاز.

The ideal gas law can be used to find any of the four variables P, V, T, and n, if the other three values are known. The equation PV = nRT can also be rearranged to calculate the molar mass and density of a gas sample.

الكتلة المولية وقانون الغاز المثالي: لإيجاد الكتلة المولية (M) لعينة غاز نستخدم القانون:

Molar Mass and the Ideal Gas Law: To find the molar mass (M) of a gas sample, use the following law:

$$M = \frac{mRT}{PV}$$

الكثافة وقانون الغاز المثالي: لإيجاد الكثافة (D) لعينة غاز نستخدم القانون:

Density and the Ideal Gas Law: To find the density (D) of a gas sample, use the following law:

$$D = \frac{MP}{RT}$$

Dalton's law of partial pressures   قانون دالتون للضغوط الجزيئية

قام دالتون بصياغة قانون سمي **بقانون دالتون للضغوط الجزيئية** الضغط الكلي لخليط من الغازات يساوي مجموع الضغوط الجزيئية لكل غاز في الخليط شرط عدم حدوث تفاعل بينهما.

Dalton formulated a law called **Dalton's Law of Partial Pressures**: The total pressure of a mixture of gases equals the sum of the partial pressures of each gas in the mixture, provided there is no chemical reaction between them.

$$P_T = P_1 + P_2 + P_3 + \ldots$$
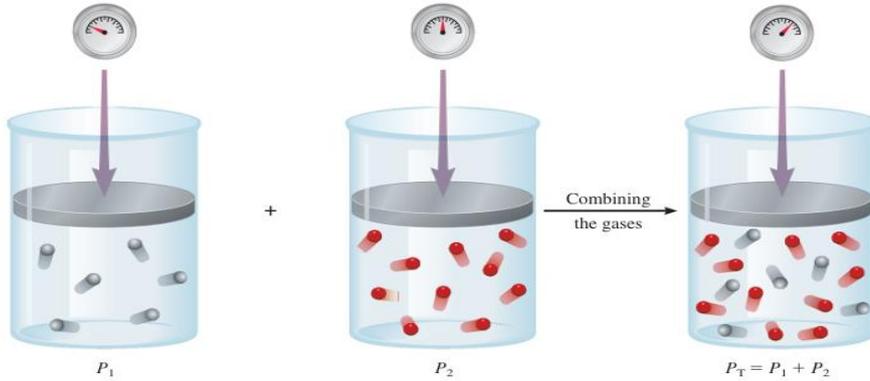
الشكل 15-5: توضيح تخطيطي لقانون دالتون للضغوط الجزيئية.

Figure 5-15: Schematic illustration of Dalton's law of partial pressures.

ويمكن إيجاد الضغط الجزئي P_i لكل غاز بمعلومية الضغط الكلي P_T والكسر المولي للغاز X_i من العلاقة:

The partial pressure P_i of each gas can be found by knowing the total pressure P_T and the mole fraction of the gas X_i from the relationship:

$$P_i = X_i P_T$$

تدريب 5-7:

عينة من الغاز الطبيعي تحتوي على 8.24 mol من CH_4 و0.421 mol من C_2H_6 و 0.116 mol من C_3H_8 إذا كان الضغط الكلي لخليط الغازات يساوي 1.37 atm فما هي قيمة الضغط الجزئي لغاز البروبان C_3H_8؟

Exercise 5-7:

A sample of natural gas contains 8.24 mol of CH_4, 0.421 mol of C_2H_6, and 0.116mol of C_3H_8. If the total pressure of the gas mixture is 1.37 atm, what is the partial pressure of propane gas C_3H_8?

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جمع الغازات فوق الماء — Collecting Gases over Water

عندما يكون ناتج التفاعل الكيميائي غازًا، يُجمع الغاز فوق الماء. على سبيل المثال، لنفترض أننا نستخدم تفاعل الزنك مع حمض الهيدروكلوريك لإنتاج غاز الهيدروجين:

When the product of a chemical reaction is a gas, the gas is collected above water. For example, suppose we use the reaction of zinc with hydrochloric acid to produce hydrogen gas:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$
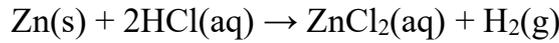
لتجميع الغاز، يُمكننا تركيب جهاز مثل الموضح في الشكل 5-16. عند تكوّن غاز الهيدروجين، يتدفق عبر الماء ويتجمع في قارورة التجميع وتعتمد هذه الطريقة على افتراض أن الغاز المُجمع لا يتفاعل مع الماء ولا تذوب أي كمية منه في الماء. ولا يكون غاز الهيدروجين المُجمع بهذه الطريقة نقيًا، بل يمتزج ببخار الماء، لذلك فإن الضغط الكلي يساوي مجموع الضغط الممارس عن طريق الهيدروجين وبخار الماء:

To collect the gas, we can set up a device like the one shown in Figure 5-16. As the hydrogen gas is formed, it flows through the water and collects in a collecting flask. This method assumes that the collected gas does not react with the water and that no amount of it dissolves in the water. The hydrogen gas collected in this way is not pure; it mixes with water vapor, so the total pressure equals the sum of the pressures exerted by the hydrogen and the water vapor:

$$P_T = P_{H_2} + P_{H_2O}$$

وبناء على ذلك، لابد أن نأخذ بالحسبان الضغط الناتج عن بخار الماء عند حساب كمية الأكسجين الناتجة.

Therefore, we must take into account the pressure exerted by the water vapor when calculating the amount of oxygen produced.
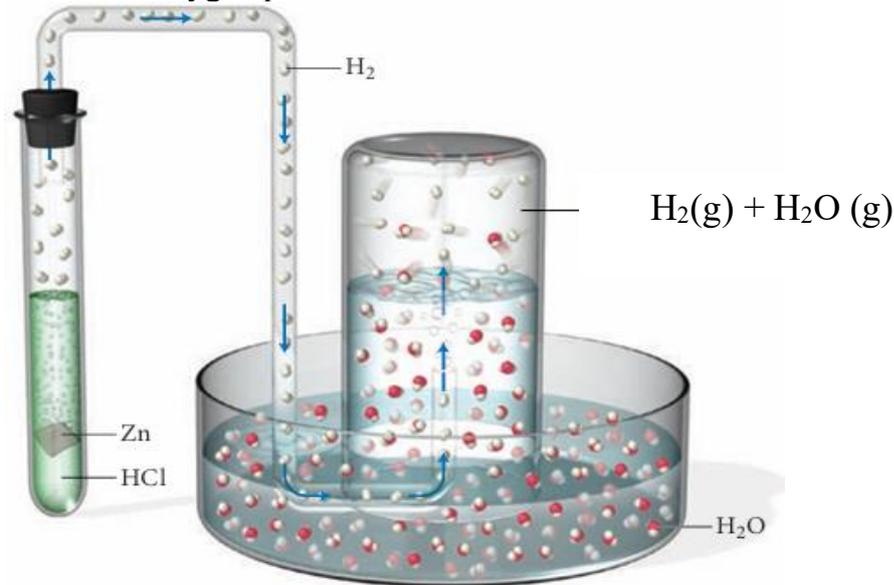
الشكل 16-5: جمع الغاز فوق الماء

Figure 5-16: Collecting a Gas over Water

تدريب 5-8:

تم جمع غاز الأكسجين الناتج عن تفكك كلورات البوتاسيوم فوق الماء. كان حجم غاز الأكسجين الناتج عند 24°C وضغط جوي 762 mmHg مساويا 128 mL . احسب كتلة الأكسجين التي تم جمعها؟ علمًا أن ضغط بخار الماء عند 24°C يساوي 22.4 mmHg

Exercise 5-8:

Oxygen gas produced by the decomposition of potassium chlorate was collected over water. The volume of oxygen gas produced at 24°C and an atmospheric pressure of 762 mmHg was 128 mL. Calculate the mass of oxygen collected. Consider that the vapor pressure of water at 24°C is 22.4 mmHg.

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الحسابات المتعلقة بالغازات	**Gas Stoichiometry**

استخدمنا في الأجزاء السابقة العلاقات بين الكميات (بالمول) والكتل (بالجرامات) للمتفاعلات والنواتج لحل أسئلة الحسابات التكافؤية. وعندما تكون المتفاعلات و/ أو النواتج في حالتها الغازية، يمكننا استخدام العلاقات بين الكميات بالمولات (n) والحجم (V) أيضاً لحل هذا النوع من الأسئلة كما هو موضح في المخطط التالي:

In the previous sections, we used the relationships between the quantities (in moles) and masses (in grams) of reactants and products to solve stoichiometric calculations questions. When the reactants and/or products are in their gaseous state, we can also use the relationships between the quantities in moles (n) and volume (V) to solve this type of question, as shown in the following diagram:

كمية المتفاعل (جرامات أو حجم) Amount of reactant (grams or volume)	→	مولات المتفاعل Moles of reactant	→	مولات الناتج Moles of product	→	كمية الناتج (جرامات أو حجم) Amount of product (grams or volume)
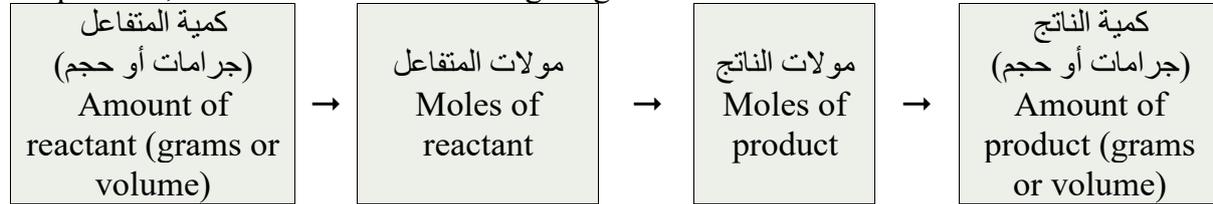
تدريب 5-9:

Exercise 5-9:

يستخدم أزيد الصوديوم (NaN$_3$) في الأكياس الهوائية للسيارات. ويؤدي اصطدام السيارة إلى تفكك NaN$_3$ كالآتي:

Sodium azide (NaN$_3$) is used in car airbags. A car collision causes the NaN$_3$ to disintegrate as follows:

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

ينفخ غاز النيتروجين المتحرر الأكياس الهوائية لتفصل بين السائق من جهة وزجاج ولوحة العدادات في السيارة من جهة أخرى. احسب حجم غاز N$_2$ عند 80°C، و 823 mmHg الناتج من تفكك 60.0 g من NaN$_3$.

The released nitrogen gas inflates the airbags, separating the driver from the car's windshield and dashboard. Calculate the volume of N$_2$ gas produced at 80°C, 823 mmHg, from the disintegration of 60.0 g of NaN$_3$.

....

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....

....

تدريب 5-1:
Exercise 5-1:

1. b

2. b

تدريب 5-2:
Exercise 5-2:

$V_1 = 1.17$ L

تدريب 5-3:
Exercise 5-3:

$T_2 = 192.5$ K

تدريب 5-4:
Exercise 5-4:

$T_2 = 273$ °C

تدريب 5-5:
Exercise 5-5:

-156.5 °C

تدريب 5-6:
Exercise 5-6:

a. $n(A) = 0.142$ mol and $n(B) = 0.071$ mol

b. $P_A = 4.0$ atm and $P_B = 2.0$ atm

تدريب 5-7:
Exercise 5-7:

$P_{propane} = 0.0181$ atm

تدريب 5-8:
Exercise 5-8:

$m(O_2) = 0.164$ g

تدريب 5-9:
Exercise 5-9:

$V(N_2) = 37.0$ L

القوى بين الجزيئات — Intermolecular forces

القوى بين الجزيئية هي قوى التجاذب بين الجزيئات، وهي المسؤولة عن التصرف غير المثالي للغازات، وأثر هذه القوى أكبر في الحالتين (السائلة والصلبة).

وهناك قوى أخرى تدعى قوى الترابط الجزيئية التي تربط بين جسيمات المادة بروابط أيونية أو تساهمية أو فلزية. إن قوى الترابط الجزيئية هي التي تثبت الذرات في الجزيء الواحد، في حين أن القوى بين الجزيئية هي المسؤولة عن الصفات العامة والفيزيائية للمادة (كدرجتي الانصهار والغليان).

Intermolecular forces are the forces of attraction between molecules. They are responsible for the non-ideal behavior of gases, and their effect is stronger in the liquid and solid states. There are also other forces called intramolecular forces, which hold the particles of a substance together through ionic, covalent, or metallic bonds.

Intramolecular forces keep the atoms bonded within a single molecule, while intermolecular forces are responsible for the general and physical properties of a substance, such as its melting and boiling points

وبشكل عام، فإن القوى بين الجزيئية أضعف من قوى الترابط الجزيئية. فنجد أن الطاقة اللازمة لتبخير السائل أقل من الطاقة اللازمة لكسر الروابط داخل جزيئاته. فمثلا، 41 kJ كافية لتبخير مول من الماء عند درجة الغليان، ولكن لكسر اثنين من روابط O-H فإننا نحتاج إلى 930 kJ للمول الواحد من الماء. إن درجات غليان المواد تعكس مدى قوة القوى بين الجزيئية. وعند درجة الغليان، يجب إمداد المادة بالطاقة اللازمة للتغلب على القوى بين الجزيئية قبل أن تحول المادة إلى الحالة الغازية. فمثلاً، إذا كانت قيمة القوى بين الجزيئية للمادة A أكبر من قيمة القوى بين الجزيئية للمادة B فهذا يعني أن درجة غليان المادة A أعلى من درجة غليان المادة B. وهذا ينطبق أيضا على درجة الانصهار؛ فكلما كانت هناك صعوبة لإبعاد الجزيئات عن بعضها، زادت درجة الانصهار. وغالباً، تزداد درجة الانصهار للمادة بزيادة قيمة القوى بين الجزيئية.

In general, intermolecular forces are weaker than intramolecular forces.

The energy required to vaporize a liquid is therefore much less than the energy needed to break the bonds within its molecules.

For example, about 41 kJ of energy is enough to vaporize one mole of water at its boiling point, but breaking the two O–H bonds in one mole of water requires about 930 kJ.

The boiling points of substances reflect the strength of their intermolecular forces.

At the boiling point, a substance must be supplied with enough energy to overcome the intermolecular forces before it can change into the gaseous state.

For instance, if substance A has stronger intermolecular forces than substance B, then the boiling point of A will be higher than that of B.

The same idea applies to the melting point: the harder it is to separate the molecules from one another, the higher the melting point.

In general, the melting point of a substance increases as the intermolecular forces become stronger

ولمعرفة خواص المواد سواء كانت في حالة السيولة أم في حالة الصلابة، يجب علينا دراسة الأنواع المختلفة من القوى بين الجزيئية، وهي: القوى ثنائية القطب، وقوى التشتت وأحيانا يطلق الكيميائيون عليها قوى فان ديرفال، والرابطة الهيدروجينية وهي أقوى أنواع القوى بين الجزيئية؛ لأن بعض العناصر فقط تشارك فيها.

To know the properties of materials, whether they are in a fluid state or in a rigid state, we must study the different types of intermolecular forces, which are: dipole, dispersion forces, sometimes called van der Waal forces, and hydrogen bonds, which are the strongest types of intermolecular forces, because only some elements are involved in them.

قوى ثنائية القطب   **Dipole Forces**

إن القوى ثنائية القطب هي قوى التجاذب الموجودة بين الجزيئات القطبية، أي بين الجزيئات التي تحمل عزماً قطبيّا وأساس هذه القوى إلكتروستاتيكي.

Dipole forces are the forces of attraction that exist between polar molecules, that is, between molecules that carry polar momentum, and the basis of these forces is electrostatic.

وكلما زاد العزم القطبي، زادت قيمة هذه القوة. يظهر الشكل 6-1 اتجاه الجزيئات القطبية في المادة الصلبة، أما في السوائل فإنه لا يكون بشكل متماسك كما هو في الصلبة، والمهم هو أن يتم الوصول إلى أكبر تجاذب بين الجزيئات من خلال اصطفافها بطريقة ما.

The greater the polar momentum, the greater the value of that force. Figure 6-1 shows the orientation of the polar molecules in the solid, but in liquids it is not as coherent as in solids, and the important thing is that the greatest attraction between the molecules is reached by aligning them in some way.
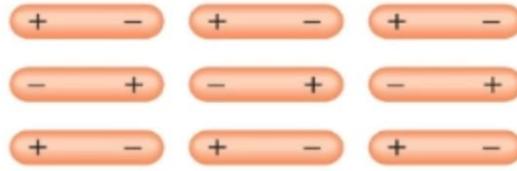
الشكل 6-1:اصطفاف الجزيئات ثنائية القطب
Figure 6-1:Alignment of dipole molecules

قوى التشتت   **Dispersion Forces**

هي قوى تجاذب ضعيفة تنشأ بين الجزيئات غير القطبية، وتنتج هذه القوى الضعيفة عن إزاحة مؤقتة في كثافة الإلكترونات في السحب الإلكترونية، وتعرف قوى التشتت أحياناً بقوى (لندن)؛ نسبة إلى الفيزيائي الألماني-الأمريكي فريتز لندن الذي كان أول من وصف هذه القوى.

These are weak gravitational forces that arise between nonpolar molecules, and these weak forces are caused by a temporary displacement in the density of electrons in electronic clouds, and the scattering forces are sometimes known as the London forces, after the German-American physicist Fritz London, who was the first to describe these forces.

وحيث أن حركة الإلكترونات دائمة داخل السحب الإلكترونية؛ فعندما يقترب جزيئان أحدهما من الآخر - ولا سيما عند تصادمهما- فإن السحب الإلكترونية لأحدهما تتنافر مع السحب الإلكترونية للجزيء الآخر، فتصبح كثافة الإلكترونات حول كل نواة - ولو للحظة - لكل سحابة إلكترونية أكبر في جهة عن الأخرى، فيشكل كل جزيّء ثنائية قطبية مؤقتة. وعند اقتراب ثنائيات الأقطاب المؤقتة بعضها من بعض تنشأ قوى تشتت ضعيفة بين مناطق الشحنات المختلفة لثنائية الأقطاب.

Since the electrons are always moving within the electron clouds, when two molecules come close to each other, especially when they collide, the electron clouds of one of them repulsively with the electron clouds of the other, so that the density of electrons around each nucleus becomes even momentarily greater than the other, forming a temporary dipole. When the temporary dipoles come close to each other, weak scattering forces are created between the different charge regions of the dipoles.
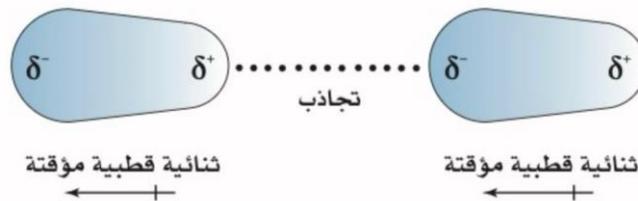
الشكل 6-2: التجاذب في قوى التشتت نتيجة القطبية المؤقتة

Figure 6-2: Attraction in the scattering forces due to temporary polarity

تنشأ قوى التشتت بين جميع الجسيمات، ولكنها تتأثر بحجم الجسيمات فهي ضعيفة في الجسيمات الصغيرة، لذلك كلما زاد حجم الجسيم تصبح قوى التشتت أكثر قوة، كما ويزداد تأثيرها مع زيادة الكتلة المولية وبالتالي ازدياد عدد الإلكترونات. مثالًا على ذلك نجد أن قوى التشتت بين جزيئات اليود أقوى من قوى التشتت بين جزيئات البروم في مجموعة الهالوجينات.

The scattering forces arise between all the particles, but they are affected by the size of the particles, as they are weak in small particles, so the larger the particle size, the stronger the scattering forces become, and their effect increases with the increase in the molar weight and thus the number of electrons. For example, the dispersion forces between iodine molecules are stronger than the dispersion forces between bromine molecules in the halogen group.

مثال 6-1

ما نوع (أنواع) القوى بين الجزيئات الموجودة بين أزواج المركبات الآتية:

Example 6-1

What are the type(s) of intermolecular forces between the following pairs of compounds:

$$C_6H_6 ، NH_3 \ (d) \quad I_2 , NO_3^- \ (c) \quad CBr_4 ، Cl_2 \ (b) \quad H_2S ، HBr \ (a)$$

(a) HBr و H_2S مركبان قطبيان. لذلك، فإن قوى التجاذب الموجودة بن الجزيئات عبارة عن ثنائيات الأقطاب إضافة إلى قوى التشتت.

(b) Cl_2 و CBr_4 مركبان غير قطبيين. لذا، فالقوى الموجودة بين الجزيئات عبارة عن قوى تشتت.

(c) I_2 و NO_3^- اليود جزيئ ثنائي الذرة متماثل. لذا، فهو جزيء غير قطبي، استناداً إلى ذلك، فإن القوى الموجودة بين I_2 وأيون NO_3^- عبارة عن قوى تشتت.

(d) NH_3 قطبي، وC_6H_6 غير قطبي. إذن، فستكون القوى بين الجزيئية قوى تشتت فقط.

مثال 6-2: اذكر نوع (أنواع) القوى بين الجزيئية في المواد الآتية:

Example 6-2: Mention the type(s) of intermolecular forces in the following materials:

(a) LiF   (b) CH_4 (c) SO_2

....

Hydrogen bond   الرابطة الهيدروجينية

تزداد درجة غليان المركبات المتشابهة في المجموعة الواحدة في الجدول الدوري بزيادة الكتلة المولية عادة، ويعود سبب هذه الزيادة في درجة الغليان إلى الزيادة في عدد الإلكترونات التي تؤدي إلى زيادة قوى التشتت.

The boiling point of similar compounds in a single group in the periodic table usually increases with an increase in molar mass, and this increase in boiling point is due to an increase in the number of electrons that increase the dispersion forces.

إن مركبات الهيدروجين في المجموعة 14 تتبع هذه الزيادة، كما هو موضح في الشكل 6-3، في حين لا تتبع مركبات الهيدروجين من عناصر المجموعات: 15،16،17 هذا المسار.

The hydrogen compounds in group 14 follow this increase, as shown in Figure 6-3, while the hydrogen compounds of group elements: 15,16,17 do not follow this pathway.

في كل سلسلة من هذه المجموعات، تكون درجة الغليان الأعلى للمركبات الأخف (HF، H_2O، NH_3) على عكس مما هو متوقع، وهذا يعود إلى قوى التجاذب بين هذه المركبات مقارنةً مع المركبات الأخرى في المجموعة نفسها. وتدعى هذه القوى الرابطة الهيدروجينية: وهي حالة خاصة من قوى ثنائي القطب التي تحدث مع ذرة هيدروجين مرتبطة مع ذرة صغيرة ذات كهروسالبية عالية، كما في الرابطة القطبية مثل N-H أو O-H أو F-H. وكما نعلم فإن ذرات N ، O ، F لها أعلى كهروسالبية في الجدول الدوري.

In each of these groups, the higher boiling point of the lighter compounds (HF, H_2O, NH_3) is the opposite of what would be expected, and this is due to the forces of attraction between these compounds compared to other compounds in the same group. These

forces are called hydrogen bonds: it is a special case of dipole forces that occur with a hydrogen atom bonded to a small atom with a high electronegativity, as in a polar bond such as N-H, O-H or F-H. As we know, the atoms N, 0, F have the highest electronegativity in the periodic table.
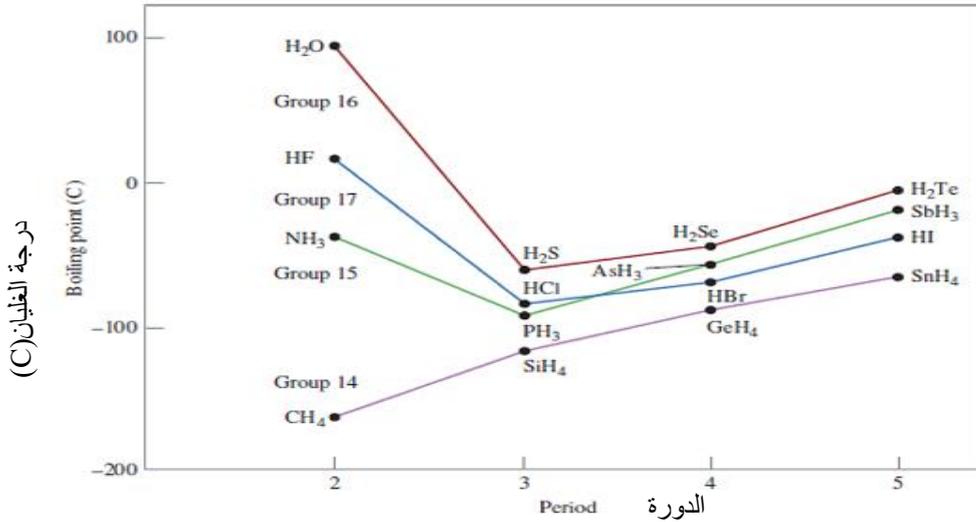
الشكل 6-3: درجات الغليان لمركبات الهيدروجين
Figure 6-3: Boiling Points of Hydrogen Compounds

This attraction can be written as follows: ويمكن أن يكتب هذا التجاذب على الشكل الآتي:
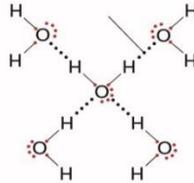
مثال 6-3
أي من المركبات الآتية يمكن أن يكوّن رابطة هيدروجينية مع الماء؟
Example 6-3
Which of the following compounds can have a hydrogen bond with water?
$$CH_3OCH_3 \ , \ CH_4 \ , \ F^- \ , \ HCOOH \ , \ Na^+$$
الحل: لا يمكن أن يكون أي من CH_4 و Na^+ رابطة هيدروجينية مع الماء. ولكن قد يكون كل من CH_3OCH_3 ، F^- ، $HCOOH$ رابطة هيدروجينية مع الماء
Solution: Neither CH_4 or Na^+ can have a hydrogen bond with water. But both CH_3OCH_3 ، F^- ، $HCOOH$ may have a hydrogen bond with water
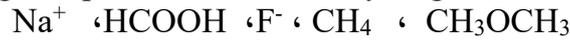
مثال6-4: أي من المركبات الآتية يمكن أن يكوّن رابطة هيدروجينية مع نفسه:
Example 6-4: Which of the following compounds can have a hydrogen bond with the same:
   (a) CH_3OH (b) C_6H_6 (c) H_2S ....

| **Properties of Liquids** | **خواص السوائل** |

القوى بين الجزيئات تؤدي إلى خواص معينة للسوائل.

Intermolecular forces lead to certain properties of liquids.

من أهم خواص السوائل:

The most important properties of fluids are:

1- الكثافة Density

كثافة السوائل أعلى من كثافة أبخرتها، كما أن كثافة المواد الصلبة أعلى من كثافة السوائل إلا في حالة الماء الذي يتميز بأن كثافته في حالة الصلابة أقل من كثافته في حالة السيولة حيث يطفو الثلج على الماء، وقد يعود ذلك إلى البناء المرتب للثلج ذي الأبعاد الثلاثة والذي يمنع تقارب الجزيئات من بعضها.

The density of liquids is higher than the density of their vapors, and the density of solids is higher than the density of liquids, except in the case of water, which is characterized by its density in the case of hardness is lower than its density in the case of liquidity, where ice floats on the water, and this may be due to the orderly construction of the three-dimensional ice, which prevents the convergence of the molecules from each other.

2- التوتر السطحي Surface Tension

يُعرَّف بأنه جذبُ الجزيئات داخل السائل بفعل القوى الجزيئية البينية في الاتجاهات جميعها، لذا، فإن محصلة القوى تكون صفراً. وعندها، فإن الجزيئات لا تتحرك، وتقوم هذه القوى بجذب الجزيئات التي على السطح ما نحو الأسفل يؤدي إلى انضغاط السطح وكأنه غشاء مرن.

It is defined as the attraction of molecules inside a liquid by intermolecular forces in all directions, so the sum of the forces is zero. The molecules do not move, and these forces attract the molecules on the surface downwards, causing the surface to compress like a flexible membrane.

الشكل 4-6: التوتر السطحي

Figure 6-4: Surface tension

3- التماسك والتلاصق   Cohesion and adhesion

قوى التماسك، وهي التجاذب بين الجزيئات المتشابهة (الماء والماء)

قوى التلاصق، وهي عبارة عن التجاذب بين الجزيئات غير المتشابهة (الماء والزجاج)

Coherent forces, which are the attraction between similar molecules (water and water)

The forces of adhesion, which is the attraction between dissimilar molecules (water and glass)

وإذا كانت قوى التلاصق أكبر من قوى التماسك كما في الماء، فإن السائل سيرتفع في الأنبوب كما هو وسيصبح سطح السائل مقعرًا.

أما إذا كانت قوى التماسك أكبر من قوى التلاصق كما في الزئبق، فإن مستوى الزئبق في الأنبوب سيكون أقل من المستوى في الوعاء، وسيصبح سطح السائل محدبًا.

If the adhesion forces are greater than the cohesive forces as in water, the liquid will rise in the pipe as it is and the surface of the liquid will become concave.

If the cohesive forces are greater than the bonding forces as in mercury, the level of mercury in the tube will be lower than the level in the vessel, and the surface of the liquid will become convex.

4- اللزوجة Viscosity

هي مقاومة المائع للجريان. حيث كلما زادت اللزوجة، أصبح جريان السائل أكثر صعوبة. وكلما زادت درجة الحرارة قلت درجة اللزوجة. كما تتأثر اللزوجة بالقوى الجزيئية البينية وأشكال الجزيئات.

It is the resistance of the fluid to flow. The higher the viscosity, the harder the fluid becomes. The higher the temperature, the lower the viscosity. The viscosity is also affected by the intermolecular forces and the shapes of molecules.

5- الميوعة fluidity

تصنف الغازات والسوائل على أنها موائع، بسبب قابليتها للانتشار والانسياب. وتنساب السوائل عادة أبطأ من انتشار الغازات عند درجة الحرارة نفسها، وذلك نتيجة تدخل القوى بين الجزيئات في عملية الانسياب، ولهذا تكون السوائل أقل ميوعة من الغازات.

Gases and liquids are classified as fluids because of their ability to diffuse and flow. Liquids typically flow more slowly than gases at the same temperature due to the intermolecular forces involved in the flow process; therefore, liquids are less fluid than gases.

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المواد الصلبة

Solids

تصنف المواد الصلبة إلى: بلورية وغير بلورية. فالثلج عبارة عن صلب بلوري، مرتب كثيراً، صلد، أيوناته أو جزيئاته أو ذراته لها مواقع محددة، مرتبة بشكل هندسي منتظم. أما الصلب غير البلوري مثل الزجاج، فإنه يفتقر إلى الترتيب المحدد والانتظام بعيد المدى كذلك.

Solids are classified into: crystalline and non-crystalline. Ice is a crystalline solid, highly arranged, solid, and its ions, molecules, or atoms have specific locations, arranged in a regular geometrical order. Amorphous steel, like glass, lacks a definite arrangement and long-term regularity as well.

المواد الصلبة البلورية

Crystalline solids

في البلورة الصلبة، تترتب الجسيمات داخل الشبكة البلورية لتكوين مكعب بثلاثة طرق مختلفة، وتمثل وحدة البناء أصغر ترتيب للذرات في الشبكة البلورية يحمل التماثل نفسه، حيث تمثل نموذج مصغر من البناء الأكبر.

In a solid crystal, the particles within the crystal lattice are arranged to form a cube in three different ways, and the unit cell represents the smallest arrangement of atoms in the crystal lattice that bears the same symmetry, as it represents a miniature model of the larger construction.

إن التركيب البنائي، وخواص المواد البلورية مثل درجة الانصهار، والكثافة، والقساوة، تحدد جميعها بناءً على قوى التجاذب التي بين الجسيمات الصغيرة. ويتم تصنيف البلورة تبعاً لنوع قوى التجاذب، سواءً أكانت؛ ذرية، أو أيونية، أو جزيئية، أو تساهمية، أو فلزية.

The structure and properties of crystalline materials such as melting point, density, and hardness are all determined by the forces of attraction between small particles. A crystal is classified according to the type of bonding/attractive forces, whether they are atomic, ionic, molecular, covalent, or metallic.

النوع Type	وحدة الجسيمات Particle Unit	خصائص الحالة الصلبة Solid-state properties	أمثلة Examples
أنواع المواد الصلبة البلورية Types of Crystalline Solids			
ذرية atomic	الذرات Atoms	لينة إلى لينة جدًا رديئة التوصيل، درجة انصهار منخفضة. Soft to very soft, poor conductivity, low melting point.	عناصر المجموعة Group Elements 18
أيونية Ionic	أيونات Ions	صلبة، هشة، درجة انصهار مرتفعة، رديئة التوصيل. Hard, brittle, high melting point, poor conductivity.	NaCl, KBr
جزيئية Molecular	جسيمات Particles	متوسطة اللين، متفاوتة في درجة الانصهار، رديئة التوصيل Medium soft, varying in melting point, poor conductivity	I_2 , H_2O ,CO_2
تساهمية شبكية Network covalent	ترتبط الذرات بروابط تساهمية Atoms are bonded by covalent bonds	صلبة جدًا، درجة انصهار مرتفعة، رديئة التوصيل. Very hard, high melting point, poor conductivity.	الألماس C الكوارتز SiO_2
فلزية Metallic	الذرات يحيط بها إلكترونات التكافؤ الحرة الحركة Atoms are surrounded by free-moving valence electrons	لينة إلى صلبة، درجة انصهار متفاوتة، قابلة للطرق والسحب، ممتازة التوصيل Soft to hard, varying melting point, malleable and ductile, excellent conductivity	جميع العناصر الفلزية

المواد الصلبة تكون أكثر استقراراً في حالة التبلور. ولكن إذا تمَّ تكوُّن المادة الصلبة بسرعة (على سبيل المثال تبريد السائل بسرعة)، فإن الذرات أو الجزيئات لا يكون لها الوقت الكافي لترتيب بعضها، ومن الممكن عندها أن تثبت في مواقع تختلف عن مواقعها المحددة. ويطلق على المادة الصلبة الناتجة غير بلورية. إن هذه المواد الصلبة غير البلورية، مثل الزجاج والمطاط والكثير من المواد البلاستيكية، تفتقر إلى الترتيب المعتاد في الأبعاد الثلاثة.

Solids are more stable when crystallized. But if a solid is formed quickly (e.g. a liquid cools rapidly), atoms or molecules don't have enough time to arrange each other, and then they can be fixed in locations different from their specific locations. The resulting solid is called an amorphous solid. These non-crystalline solids, such as glass, rubber, and a lot of plastics, lack the usual arrangement in all three dimensions.

Mixtures & Solutions — المخاليط والمحاليل

المخلوط: هو مزيج من مادتين أو أكثر، تحتفظ فيه كل مادة شاركت بتكوينه بخصائصها الكيميائية.

Mixture: It is a mixture of two or more substances, in which the material that was involved in its formation retains its chemical properties.

أنواع المخاليط:

Types of mixtures:

أولاً: المخلوط المتجانس:

هو مخلوط تمتزج مكوناته امتزاجًا تامًا بحيث لا يمكن التمييز بين مكوناته، تعرف المخاليط بالمحاليل.
المحاليل هي مخاليط متجانسة تتكون من مادتين أو أكثر تعرف بالمذيب والمذاب، المذيب هو وسط الانتشار، أما المذاب فهو المادة الصلبة التي تذوب (المادة التي تذوب مادة ذائبة والمادة التي لا تذوب مادة غير ذائبة)، وهناك أنواع متعددة من المحاليل فمنها الصلبة والسائلة والغازية؛ اعتمادًا على الحالة الفيزيائية للمذيب.

First: Homogeneous Mixture:

It is a mixture whose components are so thoroughly mixed that its components cannot be distinguished, mixtures are known as solutions.

Solutions are homogeneous mixtures consisting of two or more substances known as solvent and solute, the solvent is the diffuse medium, while the solute is the solid substance that dissolves (the substance that dissolves is a soluble substance and the substance that does not dissolve is an insoluble substance).

There are several types of solutions, including solid, liquid, and gaseous, depending on the physical state of the solvent.

ثانيًا: المخلوط غير المتجانس:

هو مخلوط لا تمتزج مكوناته معًا، بحيث يمكن التمييز بين مكوناته، وهناك نوعان من المخاليط غير المتجانسة:

Second: Heterogeneous Mixture:

It is a mixture whose components do not mix together, so that its components can be distinguished, and there are two types of heterogeneous mixtures:

1- المخلوط المعلق: جسيمات المخلوط أكبر من جسيمات الوسط، بالتالي من الممكن فصل المعلقات باستخدام الترشيح والترسيب والطرد المركزي، وتنفصل إلى طبقتين واضحتين إذا تركت دون تحريك، مثال: الوحل.

1- Suspension mixture: The particles of the mixture are larger than those of the medium; therefore, suspensions can be separated by filtration, sedimentation, or centrifugation. They separate into two distinct layers if left undisturbed. Example: mud.

2- المخلوط الغروي: جسيماته متوسطة، لا تترسب ولا يمكن فصل مكوناته بالترويق أو الترشيح. المادة الأكثر توافرًا في المخلوط تعرف بوسط الانتشار، وهناك عدة أنواع من المخاليط الغروية تصنف تبعًا للحالة الفيزيائية لوسط الانتشار.

تتميز المخاليط الغروية بوجود قوى تجاذب كهروستاتيكية فيما بينها، كما تتصادم جسيمات الوسط مع الجسيمات المنتشرة مسببة ما يعرف بالحركة البراونية وهي حركة عشوائية عنيفة تقوم بها الجسيمات المنتشرة مما يمنع ترسيبها.

2- Colloidal mixture: Its particles are medium, they do not precipitate and its components cannot be separated by marinating or filtration. The most abundant

substance in the mixture is known as the diffusion medium, and there are several types of colloidal mixtures that are classified according to the physical condition of the diffusion medium.

Colloidal mixtures are characterized by the presence of electrostatic forces of attraction between them, and the particles of the medium collide with the scattered particles, causing what is known as Brownian motion, which is a violent random movement made by the scattered particles, which prevents their deposition.

Factors Affecting Solvation العوامل المؤثرة في الذوبان

الذوبان: هي عملية إحاطة جسيمات المذاب بجسيمات المذيب.

Solvation: It is the process in which solvent particles surround solute particles .

من أهم القواعد في عملية الذوبان أن المذيبات تذيب أشباهها، لذلك نجد أن المركبات القطبية والأيونية تذوب في الماء، عن طريق اصطدام جزيئات الماء بسطح البلورة ثم تجذب أقطاب جزيئات الماء المشحونة أيونات الصوديوم وأيونات الكلوريد، وفيما يخص المركبات الجزيئية كالسكروز لا يحدث هذا التجاذب، فعندما تصطدم جزيئات الماء بسطح البلورة يتم تكوين روابط هيدروجينية بين جزيئات الماء ومجموعة الهيدروكسيل في الجزيء. أما الزيت فلا يذوب في الماء ويفسر ذلك القاعدة السابقة؛ حيث أن الماء قطبي والزيت غير قطبي.

One of the most important rules in the process of dissolving is that solvents dissolve their resembles, so we find that polar and ionic compounds dissolve in water, by colliding water molecules with the surface of the crystal and then the electrodes of the charged water molecules attract sodium ions and chloride ions, and in the case of molecular compounds such as sucrose, this attraction does not occur, so when the water molecules collide with the surface crystal hydrogen bonds are formed between the water molecules and the hydroxyl group in the molecule. As for oil, it does not dissolve in water, and this explains the previous rule, since water is polar and oil is non-polar.
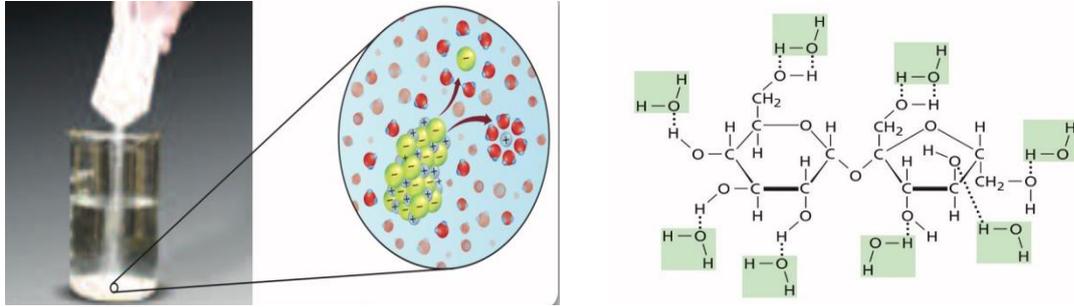
الشكل 5-6: عملية الذوبان في المركبات الأيونية والجزيئية
Figure 6-5: The process of solubilization in ionic and molecular compounds

العوامل المؤثرة في الذوبان:

1- التحريك: تسمح عملية التحريك بإبعاد الجسيمات عن بعضها البعض مما يسرع من حدوث التصادمات بين جسيمات المذاب والمذيب.

2- مساحة السطح: الزيادة في مساحة السطح تزيد من عدد التصادمات بين الجسيمات.

3- درجة الحرارة: غالبًا ما تزداد سرعة الذوبان بزيادة درجة الحرارة بسبب زيادة الطاقة الحركية للجسيمات مما يزيد من سرعة حدوث التصادمات، إلا أن ذوبان بعض المواد الأخرى، ومنها الغازات، يقل بزيادة درجة الحرارة.

Factors affecting solubility:

1-Stirring: The stirring process allows particles to be moved away from each other, which speeds up collisions between solute particles and solvent.

2-Surface area: The increase in surface area increases the number of collisions between particles.

3-Temperature: The rate of dissolution usually increases with rising temperature because the particles gain more kinetic energy, which leads to more frequent collisions. However, the solubility of some substances, including gases, decreases as the temperature increases.

الذائبية: هي أقصى كمية من المذاب يمكن أن تذوب في كمية محددة من المذيب عند درجة حرارة معينة.

Solubility: The maximum amount of solute that can be dissolved in a specific amount of solvent over a given temperature.

الشكل 6-6: منحنى الذائبية لعدد من المواد عند درجات حرارة مختلفة

Figure 6-6: Solubility curve of a number of materials at different temperatures
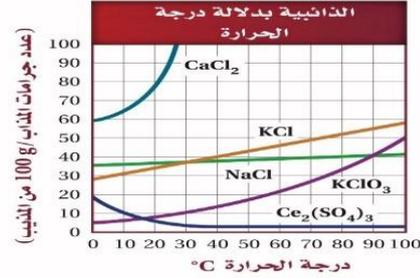
اعتمادًا على كمية المذاب المتواجدة في المحلول تظهر لدينا ثلاثة أنواع من المحاليل:

المحلول غير المشبع: يحتوي على كمية أقل من المذاب

المحلول المشبع: يحتوي على أكبر كمية من المذاب ذائبة في كمية محددة من المذيب.

المحلول فوق المشبع: يحتوي على كمية أكبر من المادة المذابة مقارنة بمحلول مشبع.

يمكن إعداد المحلول الفوق مشبع عن طريق تحضير محلول مشبع عند درجات عالية ثم تركه يبرد تدريجيًا وببطء، المحاليل فوق المشبعة غير ثابتة فعند إضافة نواة تبلور إلى محلول فوق مشبع تترسب المادة المذابة الزائدة مكونة بلورات، كذلك يمكن حدوث التبلور من خلال كشط الجزء الداخلي للإناء.

Depending on the amount of solute present in the solution, we have three types of solutions:

Unsaturated solution: contains less solute

Saturated solution: It contains the largest amount of solute dissolved in a specific amount of solvent.

Supersaturated solution: It contains a greater amount of solute as compared to a saturated solution.

The supersaturated solution can be prepared by preparing a saturated solution at high degrees and then letting it cool gradually and slowly, the supersaturated solution is not stable, when a crystallization nucleus is added to a supersaturated solution, the excess solute is deposited forming crystals, as well as crystallization can occur by scraping the inside of the vessel.

Solubility of Gases | ذائبية الغازات

تقل ذائبية غازي الأكسجين وثاني أكسيد الكربون عند درجات الحرارة المرتفعة مقارنة بدرجات الحرارة المنخفضة. وهذا سلوك متوقع لجميع المواد الغازية المذابة في المذيبات السائلة. هل تستطيع تفسير هذا السلوك؟ تذكر أن الطاقة الحركية لجسيمات الغاز تسمح للجسيمات بالتحرر أو النفاد من المحلول بسهولة أكبر عند درجات الحرارة المرتفعة. ولذلك كلما زادت درجة حرارة المحلول قلت ذائبية المذاب الغازي.

The solubility of oxygen and carbon dioxide decreases at higher temperatures compared to lower temperatures. This is expected behavior for all gaseous substances dissolved in liquid solvents. Can you explain this behavior? Remember that the kinetic energy of gas particles allows them to escape or escape from the solution more easily at higher temperatures. Therefore, the higher the temperature of the solution, the lower the solubility of the gaseous solute.

Pressure and Henry's Law | **الضغط وقانون هنري**

يؤثر الضغط في ذائبية المواد الغازية المذابة في المحاليل؛ فكلما ازداد الضغط فوق المحلول زادت ذائبية الغاز في أي مذيب. تعتمد المشروبات الغازية على هذا المبدأ؛ فهي تحتوي على غاز ثاني أكسيد الكربون المذاب في محلول مائي تحت ضغط أعلى من الضغط الجوي، وعند فتح علبة المشروب الغازي يكون ضغط غاز ثاني أكسيد الكربون داخل العلبة أعلى من الضغط الواقع خارج العلبة.

Pressure affects the solubility of gaseous substances dissolved in solutions; the higher the pressure above the solution, the greater the solubility of the gas in any solvent. Carbonated drinks operate on this principle; they contain carbon dioxide dissolved in an aqueous solution under pressure higher than atmospheric pressure. When a can of carbonated drink is opened, the pressure of the carbon dioxide inside the can is higher than the pressure outside the can.

ينص قانون هنري على " تتناسب ذائبية الغاز في سائل (S) تناسبًا طرديًا مع ضغط الغاز (P) الموجود فوق السائل عند ثبوت درجة الحرارة". فعندما تكون قارورة المشروب الغازي مغلقة، يعمل الضغط الواقع فوق المحلول على إبقاء غاز ثاني أكسيد الكربون ذائبًا في المحلول. ويمكن تمثيل هذه العلاقة كما يلي:

Henry's Law states that "the solubility of a gas in a liquid (S) is directly proportional to the pressure (P) of the gas above the liquid at a constant temperature." When the bottle of soft drink is closed, the pressure above the solution keeps the carbon dioxide dissolved. This relationship can be represented as:

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

Solution Concentration | تركيز المحلول

تركيز المحلول: مقياس يعبر عن كمية المذاب الذائبة في كمية محددة من المذيب أو المحلول.

Solution Concentration: A measure that expresses the amount of solute dissolved in a specific amount of solvent or solution

كيفية التعبير عن التركيز: يمكن التعبير عن التركيز وصفيًا (مركزًا أو مخففًا) أو كميًا باستخدام عدد من الطرق التي تُعبر عن التركيز كميًا ويمكن تحديد الطريقة المناسبة للاستخدام تبعًا لنوع المحلول.

How to express concentration: Concentration can be expressed descriptively (concentrated or diluted) or quantitatively using a number of methods that quantitatively express concentration and the appropriate method for use can be determined depending on the type of solution.

النسبة	وصف التركيز Focus Description
$\text{Percentage by mass} = \dfrac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$ $\dfrac{\text{كتلة المذاب}}{\text{كتلة المحلول}} \times 100 = $ النسبة المئوية بالكتلة	%m/m النسبة المئوية بالكتلة Percentage in terms of mass
$\text{Percentage by volume} = \dfrac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$ $\dfrac{\text{حجم المذاب}}{\text{حجم المحلول}} \times 100 = $ النسبة المئوية بالحجم	%v/v النسبة المئوية الحجمية Percentage in terms of volume
$M = \dfrac{\text{moles of solute}}{\text{liters of solution}}$ $\dfrac{\text{عدد مولات المذاب}}{\text{حجم المحلول باللتر}} = $ المولارية (التركيز المولاري)	M المولارية (التركيز المولاري) Molarity (molar concentration)
$m = \dfrac{\text{moles of solute}}{\text{mass of solvent (kg)}}$ $\dfrac{\text{عدد مولات المذاب}}{\text{كتلة المذيب بالكيلوجرام}} = $ المولالية (التركيز المولالي)	m المولالية (التركيز المولالي) Molality (molal concentration)
$X_A = \dfrac{n_A}{n_A + n_B}$ $\dfrac{\text{عدد مولات المكوّن}(A)}{\text{مجموع عدد المولات لجميع المكوّنات}} = $ الكسر المولي لمكوّن(A)	الكسر المولي Molar fraction

Example 6-5:   مثال6-5:

خليط كتلته 5.00 g من كبريتيد البوتاسيوم وكلوريد البوتاسيوم يحتوي على 2.80 g من البوتاسيوم. ما النسبة المئوية الكتلية لكبريتيد البوتاسيوم في هذا الخليط؟

A 5.00 g mixture of potassium sulfide and potassium chloride contains 2.80 g potassium. What percentage by mass of the mixture is potassium sulfide?

A	B	C	D
13.8%	19.2%	44.0%	96.1%

$$m_1 + m_2 = 5.00 \text{ g}$$

$$\frac{39.10 \times 2}{39.10 \times 2 + 32.06} m_1 + \frac{39.10}{74.55} m_2 = 2.80 \text{ g}$$

we get $m_1 = 0.99$ g and $m_2 = 4.01$ g.

$$\frac{0.99 \text{ g}}{5.00 \text{ g}} \times 100.0\% = 19.2\%$$

Example 6-6:   مثال 6-6:

ما حجم غاز الأمونيا بوحدة dm^3 (عند الظروف العادية RTP) الذي يجب امتصاصه في 1.000 dm^3 من الماء المقطر لتحضير محلول 10 m/m%؟ ما حجم المحلول إذا كانت كثافته 0.957 g/cm^3؟

How many dm^3 ammonia gas (under RTP conditions) should be absorbed in 1.000 dm^3 distilled water so as to prepare a 10 m/m% solution? what will be the volume of the solution if its density is 0.957 g/cm^3?

....
....
....
....
....

Colligative Properties of Solutions	**الخواص الجامعة للمحاليل**

الخواص الجامعة للمحاليل : خواص فيزيائية للمحاليل تتأثر بعدد جسيمات المذاب وليس بطبيعتها.
وتشمل: الانخفاض في الضغط البخاري، الارتفاع في درجة الغليان، الانخفاض في درجة التجمد، الضغط الأسموزي.

Aggregate properties of solutions: The physical properties of solutions are affected by the number of particles in the solution and not by their nature.
They include: decrease in vapor pressure, high boiling temperature, decrease in freezing, osmotic pressure.

ولنتذكر: هناك نوعان من المحاليل المائية كما تعرفنا سابقًا:

1- مواد متأينة إلكتروليتية (توصل التيار الكهربائي)، تتغير عدد جسيماته الناتجة في المحلول المائي، **مثال** كلوريد الصوديوم تنتج 2 mol من الجسيمات Na^+ و Cl^- بدلًا من 1 mol من NaCl.
2- مواد غير متأينة (لا توصل التيار الكهربائي) يبقى عدد المولات كما هو في المحلول المائي.

Let us remember: There are two types of aqueous solutions as we knew earlier:
  1- Electrolytic ionized substances (conducting electric current), the number of particles produced in an aqueous solution change, e.g. sodium chloride produces 2 mol of Na^+ and Cl^- particles instead of 1 mol of NaCl.

2- Non-ionized materials (do not conduct electricity) so that the number of moles remains the same in the aqueous solution.

أولًا: الانخفاض في الضغط البخاري

الضغط البخاري: هو الضغط الناتج عن بخار السائل عندما يكون في حالة اتزان ديناميكي مع سائله في وعاء مغلق عند درجة حرارة وضغط ثابتين، وعند هذه النقطة تتساوى سرعتي التبخر والتكثف.

الانخفاض في الضغط البخاري: عند ثبات كمية المذيب وتركيز المذاب، كلما ازداد عدد جسيمات المذاب في المحلول قلَّ الضغط البخاري للمذيب.

First: Decrease in vapor pressure

Vapor pressure: The pressure produced by the vapor of a liquid when it is in dynamic equilibrium with its liquid in a closed vessel at a constant temperature and pressure, at which point the velocities of evaporation and condensation are equal.

Vapor Pressure Lowering: Assuming the amount of solvent and the solute concentration are constant, the greater the number of solute particles in the solution, the lower the solvent's vapor pressure.

مثال6-7: رتب المركبات المتأينة التالية تصاعديًا حسب تأثيرها في الضغط البخاري:

Example 6-7 : Arrange the following ionized compounds in ascending order according to their effect on vapor pressure:

(a) Na_2SO_4 (b) $AlCl_3$ (c) NaCl

الحل: c ثم a ثم b

Solution: c , a,   then b

ثانيًا: الارتفاع في درجة الغليان:

درجة الغليان: هي درجة الحرارة التي يتعادل فيها الضغط البخاري مع الضغط الجوي.

الارتفاع في درجة الغليان: هو الفرق بين درجة غليان المحلول ودرجة غليان المذيب النقي.

Second: Boiling Point Elevation:

Boiling Point: The temperature at which the vapor pressure is equivalent to the atmospheric pressure.

Boiling Point Elevation: It is the difference between the boiling point of a solution and the boiling point of a pure solvent.

$$\Delta T_b = K_b \times m$$

ثالثًا: الانخفاض في درجة التجمد:

الفرق بين درجة تجمد المحلول ودرجة تجمد المذيب النقي.

Third: Freezing Point Depression:

The difference between the freezing point of the solution and the degree of freezing of the pure solvent.

$$\Delta T_f = K_f \times m$$

مثال 6-8: يستعمل إيثيلين جلايكول EG, $CH_2(OH)CH_2(OH)$ ، عادة بوصفه مادة مانعة لتجمد الماء في السيارات، وهي ذائبة في الماء، وغير متطايرة إلى حد ما (درجة الغليان197°C). احسب درجة تجمد المحلول

أولمبياد العلوم والرياضيات الوطني

الذي يحوي g 651 من هذه المادة في g 2505 ماء. هل من المفيد الاحتفاظ بهذه المادة في سيارتك خلال فصل الصيف؟ الكتلة المولية للإيثلين جلايكول تساوي g 62.01 .

Example 6-8: Ethylene glycol EG, CH₂(OH)CH₂(OH), usually used as a water antifreeze agent in automobiles, is water-soluble, and is fairly non-volatile (boiling point 197°C). Calculate the freezing point of a solution containing 651 g of this substance in 2505 g water. Is it useful to keep this substance in your car during the summer? The molar mass of ethylene glycol is 62.01 g.

K$_f$= 1.86 °C/*m* , **K$_b$= 0.52 °C/*m***

الحل:

يمكننا حساب الانخفاض في درجة التجمد للمحلول باستخدام

We can calculate the reduction in freezing of a solution using

$$\Delta T_f = K_f \times m$$

لحساب مولالية المحلول نحتاج أن نحسب عدد مولات *EG* وكتلة المذيب بالكيلو جرامات.

نحسب الكتلة المولية للإيثلين جلايكول. ومن ثم يتم تحويل كتلة المذيب إلى الكيلو جرام kg 2.525 ويتم حساب المولالية كما يأتي:

To calculate the molar of the solution, we need to calculate the number of moles of EG and the mass of the solvent in kilograms.

We calculate the molar mass of ethylene glycol. The mass of the solvent is then converted to 2.525 kg and the molar is calculated as follows:

$$651 \ g \ EG \ X \ \frac{1 mol \ EG}{62.07 \ g \ EG} = 10.5 \ mol \ EG$$

المولالية = مولات المذاب/ كتلة المذيب kg

Molarity = Moles of Solute / Solvent Mass kg

$$\frac{10.5 \ mol \ EG}{2.505 \ Kg \ H2O} = 4.19 \ m$$

$$\Delta Tf = Kf \ m = (1.86°C/m)(4.19 \ m) = 7.79°C$$

ولكون الماء النقي يتجمد عند درجة 0 °C فسيتجمد المحلول عند 7.79°C-

Since pure water freezes at 0°C , the solution will freeze at -7.79°C

و نستطيع حساب الارتفاع في درجة الغليان نفسها حسب المعادلة الآتية:

We can calculate the rise in the boiling point itself according to the following equation:

$$\Delta Tb = Kb \ m = (0.52°C/m)(4.19 \ m) = 2.2°C$$

ولأن المحلول سيغلي عند (100+2.2) أو102.2°C ، فمن الأفضل الاحتفاظ بالمادة المانعة للتجمد في السيارة خلال فصل الصيف لمنع الماء من الغليان.

Because the solution will boil at 100+2.2 or 102.2°C, it is best to keep the antifreeze in the car during the summer to prevent the water from boiling.

مثال6-9: احسب درجتي الغليان والتجمد لمحلول يحوي g 478 من الإيثلين جلايكول (C₂H₆O₂) في g 3202 ماء.

Exercise 6-9: Calculate the boiling and freezing of a solution containing 478 g of ethylene glycol (C₂H₆O₂) in 3202 g water.

K$_f$= 1.86 °C/*m* , **K$_b$= 0.52 °C/*m***

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تدريب 6-1

ما تركيز H_2O_2 في المحلول الذي يحتوي على 30.0% من كتلة بيروكسيد الهيدروجين وكثافته $1.11 g/cm^3$.

What is the concentration of H_2O_2 in a solution that is 30.0% by mass hydrogen peroxide and has a density of 1.11 g cm³?

A	B	C	D
9.79 M	12.6 M	18.5 M	32.6 M

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تدريب 6-2

تم خلط $100 cm^3$ من محلول حمض الهيدروكلوريك تركيزه $0.100 mol/dm^3$ وكثافة تساوي $1.000 g/cm^3$ مع $100 cm^3$ من محلول نترات الفضة تركيزه $0.100 mol/dm^3$ وكثافة تساوي$1.010 g/cm^3$. تكون محلول من عملية الخلط كثافة $1.015 g/cm^3$. حدد مولارية هذا المحلول بعد تصفية المحلول من الراسب المتكون؟

100 cm³ of a solution of hydrochloric acid with a concentration of 0.100 mol/dm³ and a density equal to 1.000 g/cm³ was mixed with 100 cm³ of a solution of silver nitrate with a concentration of 0.100 mol/dm³ and a density equal to 1.010 g/cm³. The mixing process formed a solution with a density of 1.015 g/cm³. Determine the molarity of this solution after filtering the solution from the precipitate?

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Example الأمثلة

<u>**6-2**</u>

a) قوى ثنائية القطب/ b) قوى تشتت c) قوى تشتت وقوى ثنائية القطب

(a) dipole forces/ (b) dispersion forces (c) dispersion forces and dipole forces

<u>**6-4**</u>

a

<u>**6-6**</u>

the mass of the solution formed $m_s = 1000\ g + m(NH_3)$

$$\frac{m(NH_3)}{m_s} = \frac{10}{100} = 0.1 = \frac{m(NH_3)}{1000 + m(NH_3)} \Rightarrow m(NH_3) = 111.1\ g$$

$$n_{NH_3} = \frac{111.1}{17.0} = 6.535\ mol$$

$$V_m = \frac{V}{n} \rightarrow V = n \times V_m = 6.535 mol \times \frac{24.5 dm^3}{mol} = 160.1 dm^3$$

$$m_s = 1000 + 111.1 = 1111.1\ g$$

$$V_s = \frac{1111.1g}{0.957\frac{g}{cm^3}} = 1161\ cm^3$$

<u>**6-9**</u>

محلول إيثيلين جلايكول غير متأين، غير متطاير:(i=1)

- $n = \frac{478}{62.07} \approx 7.701\ mol$

- $m = \frac{7.701}{3.202} \approx 2.405\ m$ المولالية

$$\Delta T_b = iK_b m = 0.512 \times 2.405 \approx 1.231\ °C \Rightarrow T_b \approx 101.23\ °C$$

$$\Delta T_f = iK_f m = 1.86 \times 2.405 \approx 4.47\ °C \Rightarrow T_f \approx -4.47\ °C$$

Exercise التدريبات

6-1

A

$$1.11\ \frac{g}{cm^3} \times \frac{30.0\%}{100\%} = 0.33\ \frac{g}{mL}$$

$$0.333\ \frac{g}{mL} \times \frac{1}{34.01} \times \frac{1000mL}{L} = 9.79M$$

6-2

The reaction : $HCl + AgNO_3 \rightarrow AgCl + HNO_3$

$$n_{AgNO_3} = M_{AgNO_3} \times V = \frac{0.1000mol}{dm^3} \times 0.1000 dm^3 = 10^{-2} mol$$

$$n_{HCl} = M_{HCl} \times V = \frac{0.1000mol}{dm^3} \times 0.1000 dm^3 = 10^{-2} mol$$

$$10^{-2}\ HCl + 10^{-2}\ AgNO_3 \rightarrow 10^{-2}\ AgCl + 10^{-2}\ HNO_3$$

$$m_{AgCl} = n_{AgCl} \times M_w = 10^{-2} \times 143.32 = 1.4332g$$

$$m_{AgNO_3} = D_{AgNO_3} \times V = \frac{1.010g}{cm^3} \times 100cm^3 = 101g$$

$$m_{HCl} = D_{HCl} \times V = \frac{1.000g}{cm^3} \times 100cm^3 = 100g$$

the solution formed $= 100 + 101 - 1.4332 = 199.5668\ g$

$$V_s = \frac{m_s}{D_s} = \frac{199.5668}{1.015} = 196.618cm^3$$

$$c_{HNO_3} = \frac{n_{HNO_3}}{V_{HNO_3}} = \frac{10^{-2}mol}{0.196618\ dm^3} = 0.051M$$

أولمبياد العلوم والرياضيات الوطني

PERIODIC TABLE

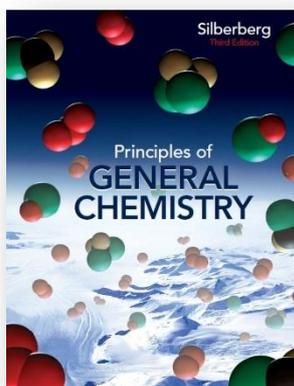|	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
	I.A																	VIII. A
1.	2.1 **1** **H** 1.0	II. A											III. A	IV. A	V. A	VI. A	VII. A	**2** **He** 4.0
2.	1.0 **3** **Li** 6.9	1.5 **4** **Be** 9.0						EN* atomic number **Chem. symbol** relative atomic mass					2.0 **5** **B** 10.8	2.5 **6** **C** 12.0	3.0 **7** **N** 14.0	3.5 **8** **O** 16.0	4.0 **9** **F** 19.0	**10** **Ne** 20.2
3.	0.9 **11** **Na** 23.0	1.2 **12** **Mg** 24.3	III. B	IV. B	V. B	VI. B	VII. B	VIII. B			I. B	II. B	1.5 **13** **Al** 27.0	1.8 **14** **Si** 28.1	2.1 **15** **P** 31.0	2.5 **16** **S** 32.0	3.0 **17** **Cl** 35.5	**18** **Ar** 40.0
4.	0.8 **19** **K** 39.1	1.0 **20** **Ca** 40.1	1.3 **21** **Sc** 45.0	1.5 **22** **Ti** 47.9	1.6 **23** **V** 50.9	1.6 **24** **Cr** 52.0	1.5 **25** **Mn** 54.9	1.8 **26** **Fe** 55.8	1.8 **27** **Co** 58.9	1.8 **28** **Ni** 58.7	1.9 **29** **Cu** 63.5	1.6 **30** **Zn** 65.4	1.6 **31** **Ga** 69.7	1.8 **32** **Ge** 72.6	2.0 **33** **As** 74.9	2.4 **34** **Se** 79.0	2.8 **35** **Br** 79.9	**36** **Kr** 83.8
5.	0.8 **37** **Rb** 85.5	1.0 **38** **Sr** 87.6	1.3 **39** **Y** 88.9	1.4 **40** **Zr** 91.2	1.6 **41** **Nb** 92.9	1.8 **42** **Mo** 95.9	1.9 **43** **Tc** [98]	2.2 **44** **Ru** 101.1	2.2 **45** **Rh** 102.9	2.2 **46** **Pd** 106.4	1.9 **47** **Ag** 107.9	1.7 **48** **Cd** 112.4	1.7 **49** **In** 114.8	1.8 **50** **Sn** 118.7	1.9 **51** **Sb** 121.8	2.1 **52** **Te** 127.6	2.5 **53** **I** 126.9	**54** **Xe** 131.3
6.	0.7 **55** **Cs** 132.9	0.9 **56** **Ba** 137.3	1.1 **57** **La** 138.9	1.3 **72** **Hf** 178.5	1.5 **73** **Ta** 180.9	1.7 **74** **W** 183.8	1.9 **75** **Re** 186.2	2.2 **76** **Os** 190.2	2.2 **77** **Ir** 192.2	2.2 **78** **Pt** 195.1	2.4 **79** **Au** 197.0	1.9 **80** **Hg** 200.6	1.8 **81** **Tl** 204.4	1.8 **82** **Pb** 207.2	1.9 **83** **Bi** 209.0	2.0 **84** **Po** [209]	2.2 **85** **At** [210]	**86** **Rn** [222]
7.	0.7 **87** **Fr** [223]	0.9 **88** **Ra** [226]	1.1 **89** **Ac** [227]	**104** **Rf** [261]	**105** **Db** [262]	**106** **Sg** [266]	**107** **Bh** [264]	**108** **Hs** [269]	**109** **Mt** [268]	**110** **Ds** [271]	**111** **Rg** [272]	**112** **Cn** [285]	**113** **Nh** [284]	**114** **Fl** [289]	**115** **Mc** [289]	**116** **Lv** [293]	**117** **Ts** [294]	**118** **Og** [294]

1.1 **58** **Ce** 140.1	1.1 **59** **Pr** 140.9	1.1 **60** **Nd** 144.2	1.1 **61** **Pm** [145]	1.2 **62** **Sm** 150.4	1.2 **63** **Eu** 152.0	1.2 **64** **Gd** 157.3	1.2 **65** **Tb** 158.9	1.2 **66** **Dy** 162.5	1.2 **67** **Ho** 164.9	1.2 **68** **Er** 167.3	1.2 **69** **Tm** 168.9	1.1 **70** **Yb** 173.0	1.2 **71** **Lu** 175.0
1.3 **90** **Th** 232.0	1.5 **91** **Pa** 231.0	1.4 **92** **U** 238.0	1.3 **93** **Np** [237]	1.3 **94** **Pu** [244]	1.3 **95** **Am** [243]	1.3 **96** **Cm** [247]	1.3 **97** **Bk** [247]	1.3 **98** **Cf** [251]	1.3 **99** **Es** [252]	1.3 **100** **Fm** [257]	1.3 **101** **Md** [258]	1.3 **102** **No** [259]	1.3 **103** **Lr** [262]

* EN: electronegativity

- وزارة التعليم . سلسلة مقررات الكيمياء في المرحلة الثانوية (نظام المسارات) ، المملكة العربية السعودية ، 2025 .

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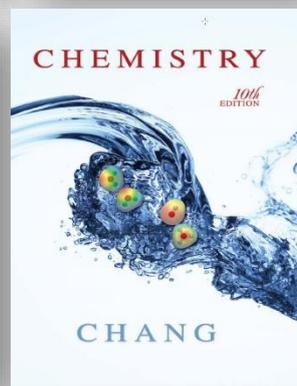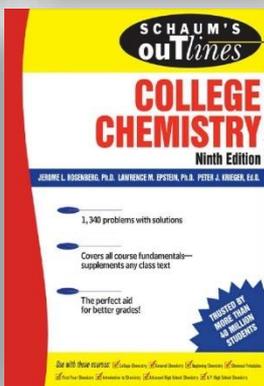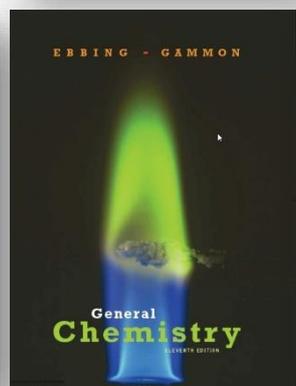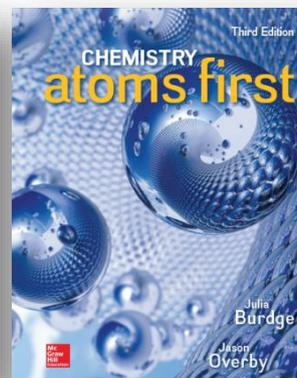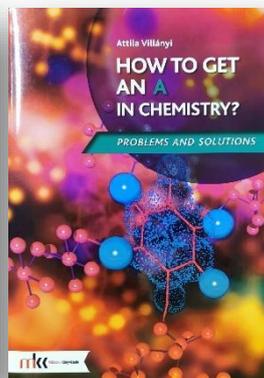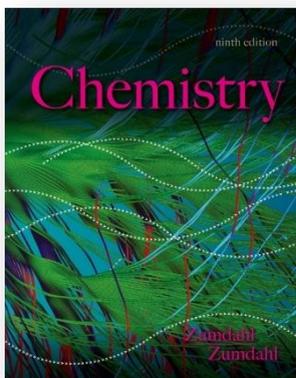
Physics

CONTENTS

1 Dynamics: Newton's Laws

In previous chapters on mechanics, we described motion in terms of displacement, velocity, and acceleration without investigating the underlying causes. We did not ask ourselves: What causes motion? Why does one object remain stationary while another moves? What makes an object accelerate or decelerate?

To answer these questions, we must study force and relate it to motion - a field known as dynamics. In this chapter, we will define force and discuss its various types, including weight, normal forces, and friction forces. We will also examine Newton's three laws of motion, formulated over three centuries ago by Isaac Newton, which marked a turning point in our understanding of motion. Finally, we will apply these laws to real-world problems to solidify our comprehension.

The force (F) is one of the fundamental concepts in physics. It describes an interaction that can change the state of motion or the shape of an object. When a force acts on a stationary object, it can cause it to move, and when it acts on a moving object, it can change its speed or direction. A force is not a tangible thing, but an external influence whose effect appears through the acceleration or deformation of the object.

Force is measured in the International System of Units (SI) using the newton (N), and it is a vector quantity, meaning it has magnitude, direction, and a point of application. Forces in nature vary, including gravity that pulls objects toward the Earth, tension in ropes, the normal force from surfaces, friction that resists motion, and the applied force resulting from direct pushing or pulling.

The study of forces forms the foundation of dynamics, as it is closely related to Newton's laws of motion, which explain how and why objects move or remain at rest.

- The force is a vector quantity, that mean it has a direction and a value, and it follows the rules of vector addition discussed before, we can represent any force on a diagram by an arrow, the direction of the arrow is the direction of the force, and its length is drawn proportional to the magnitude of the force.

- Forces do not always cause motion, however. For example, as you sit reading this book, a gravitational force acts on your body and yet you remain stationary. As a second example, you can push (in other words, exert a force) on a large boulder and not be able to move it.

- Force is measured in newton (N) in the International System of Units SI, and in (dyne) in the French system CGS: 1 dyne=10^{-5} N

Classifications of Forces

- Contact forces: Require contact between two bodies, such as tension forces.
- Field forces: The effect occurs through a field without direct contact, such as electrical attraction forces or gravitational attraction between masses.

Important Concepts:

System: It is an object or objects under study.

Environment or surroundings: everything that surrounds the system and Effects on it with forces.

Free-Body Diagram

It is prepared with the following steps A diagrammatic representation,

Abbreviate the system as a point and put it in the origin of the system coordinates.

Draw the forces acting on the system as vectors, with care of lengths (proportional to values) and directions.

Forces in directions $+y, +x$: positive   Force in directions $-y, -x$: negative

Example 1-1

The following figure shows a free-body diagram of the forces acting on a box moving to the right under the influence of a force pulling it to the right.
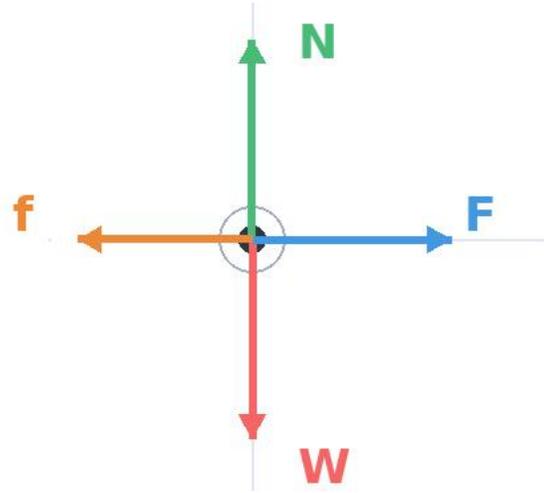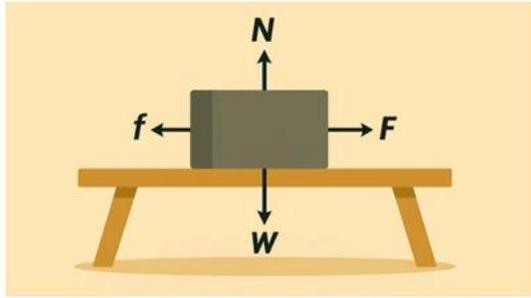
Note that we are only drawing the forces acting on the box, and we are not concerned with the forces acting on the table by the ground or by the box.

1.2 Newton's First Law

What is the relationship between force and motion?

Aristotle (384–322 BC) believed that a force is necessary to keep an object moving on a horizontal surface. He considered rest to be the natural state of an object and assumed that a body requires a continuous force acting on it to remain in motion. He also argued that the greater the applied force, the greater the object's speed.

Nearly two thousand years later, Galileo Galilei disagreed with Aristotle's view. He argued that the natural state of a body is to remain in uniform motion - that is, to move with a constant velocity - or to remain at rest if no external forces act upon it.

To illustrate, imagine an object placed on a perfectly smooth surface - a table coated with an ideal frictionless oil layer. Once the object is set in motion, it will continue moving at a constant speed without being affected by any frictional force. This brilliant idea of Galileo, the concept of eliminating friction, provided a profound foundation for understanding the physical world.

Building upon Galileo's insight, Sir Isaac Newton developed his monumental theory of motion, summarized in his three famous laws of motion presented in his great work "Philosophiea Naturalis Principia Mathematica" published in 1687.

Newton acknowledged Galileo's influence, as Newton's First Law of Motion closely aligns with Galileo's conclusions, and it is also known as the Law of Inertia.

An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force.

Notice how Newton's first law clearly applies to the box when it moves at constant velocity in a straight line, and to the stationary vase.
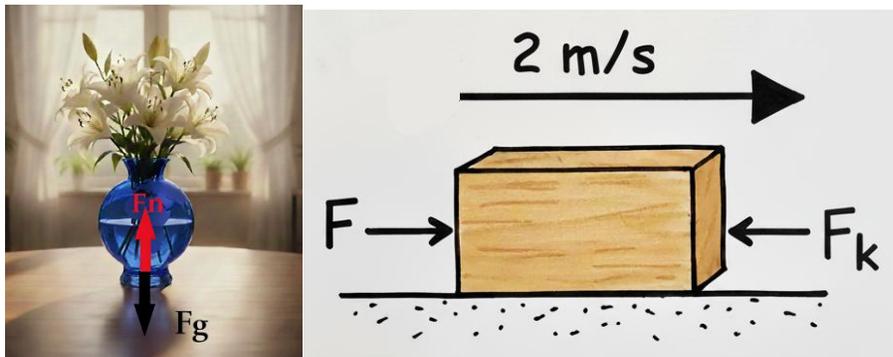
And in both cases $\sum \vec{F} = 0$ and $a = 0$

$v = 0$ or $v = constamt$

The objects then are in: Transitional Kinetic Equilibrium.

1.2.1 Inertial Frames

We simply mean by reference frame: the observer of an event, a special group of reference frames called inertial reference frames, which are non-accelerate.

Since Newton's first law relates only to objects without acceleration, it is only true in static frames.

Newton's first law is not held in every reference frame. For example, if your reference frame is an accelerating car, an object such as a cup resting on the dashboard may begin to move toward you (it stayed at rest as long as the car's velocity remained constant). The cup accelerated toward you, but neither you nor anything else exerted a force on it in that direction.

In accelerating reference frames, Newton's first law does not hold. Physics is easier in reference frames in which Newton's first law does hold, and they are called inertial reference frames (the law of inertia is valid in them). For most purposes, we usually make the approximation that a reference frame fixed on the Earth is an inertial frame. (This is not precisely true, due to the Earth's rotation, but usually it is close enough).

Any reference frame that moves with constant velocity (say, a car or a train) relative to an inertial frame is also an inertial reference frame. Reference frames where the law of inertia does not hold, such as the accelerating reference frames discussed above, are called non-inertial reference frames.
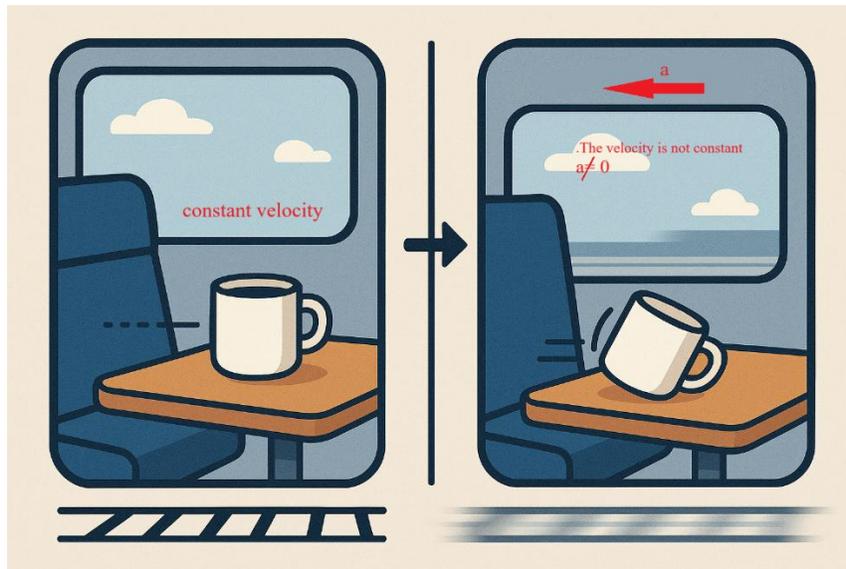
1.2.2   Inertia

The tendency of an object to remain in its state of rest or uniform motion in a straight line is called inertia.

For example, it is difficult to set a stationary object in motion, to stop a moving object, or to change its velocity sideways out of a straight-line path.

Inertia depends on the mass of the object; it increases as the mass increases.

Mass is an inherent property of an object and does not depend on the surrounding medium or on the method used to measure it.

Newton used the term mass as a synonym for "quantity of matter." However, this notion is not very precise, since the concept "quantity of matter" itself is not well defined.

The following phenomena can be explained based on the concept of inertia:

When a car suddenly stops, passengers tend to lurch forward.

This happens because their bodies try to continue moving with the same speed and direction as before the car stopped — that is, their bodies resist the change in their state of motion.

When a tablecloth is pulled quickly from under dishes, the dishes remain almost in place.
This occurs because the dishes have inertia, which makes them resist the sudden change from rest.

When a stationary ball is kicked, a force is required to set it in motion.
The greater the mass of the ball, the harder it is to move, because its inertia is greater.

When moving a heavy object such as a water tank or a large box, it is difficult to start or stop its motion quickly. This is because inertia increases directly with mass.

1.3 Newton's second Law

Newton's first law explains what happens to an object when no forces act on it. It either remains at rest or moves in a straight line with constant speed. Newton's second law answers the question of what happens to an object that has a nonzero resultant force acting on it.

 Newton's second law states that:

When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

The equation:

$$\sum F = ma$$

$$\sum F_y = ma_y \quad \sum F_x = ma_x$$

Note the proportionality in the example of a cart moving under a horizontal force on a surface of negligible friction, study the figure.
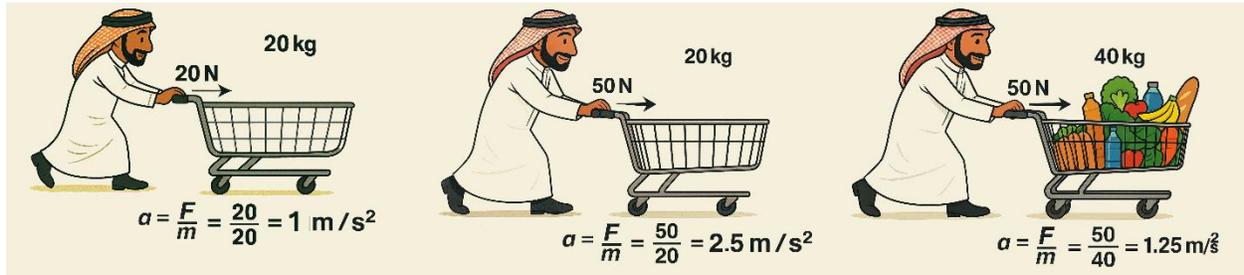
Important Notes

- We apply Newton's second law to the net force, not to the single forces.
- We assume that objects can be modeled as particles (point masses) so that we need not worry about rotational motion.

Think:

- Is the acceleration always in the direction of the net force? And why?
- Write newton (N) in terms of base units?
- A car is moving north at a constant speed, what is the direction of the net force acting on it?

Example 1-2

A box of mass $3.0\ kg$ moves horizontally on a smooth surface under the forces shown. Calculate the horizontal acceleration. (Neglect friction; consider only horizontal components.)

    (a) Single horizontal force: $F\ =\ 9.0\ N$ to the right.

$$a\ =\ F/m\ =\ 9.0\ /\ 3.0\ =\ 3.0\ m/s^2 \text{ (to the right)}.$$

(b) Single force: $F = 10.0\ N\ at\ 40.0°$ above the horizontal.

F = 10.0 N, 40°
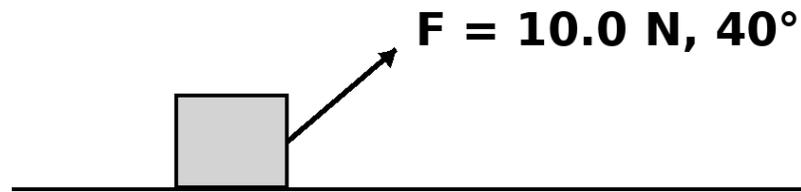
$$a = (F\cos 40°)/m = (10.0\ cos\ 40°)/3.0 = 2.55\ m/s^2 \text{ (to the right)}.$$

Example 1-3

What average net force is required to bring a 1500kg car to rest from a speed of 100km/h within 55 m?

Given:

$$m = 1500\ \text{kg},\ v_i = 100\ \text{km/h} = \frac{100 \times 1000}{3600} = 27.78\ \text{m/s},\ v_f = 0\ \text{m/s},\ d = 55\ \text{m}$$

Find acceleration using kinematics

$$v_f^2 = v_i^2 + 2ad$$
$$0 = (27.78)^2 + 2a(55)$$
$$a = -\frac{(27.78)^2}{2(55)} = -7.0\ \text{m/s}^2$$

Find the net force

$$F_{\text{net}} = ma = 1500 \times (-7.02) = -1.0 \times 10^4\ \text{N}$$

Exercise 1: A hockey puck of mass 0.40 kg slides on a smooth horizontal surface of ice. Two forces act on it: the first $F_1 = 7.5$ N at a standard angle of $-30.0°$, and the second $F_2 = 6.0$ N at a standard angle of $30.0°$. Find the acceleration of the puck using unit vectors.

1.3.1 Weight

It is the magnitude of the Earth's gravitational force on an object. Its direction is always toward the center of the Earth, meaning perpendicular to the Earth's surface.

$$F_g = W = mg$$

Where:

W: Weight   m: Mass of the object   g: Acceleration due to Earth's gravity

Remember that: The value of gravitational acceleration at the Earth's surface is approximately 9.8 m/s², and its magnitude decreases with altitude, meaning that weight decreases with altitude.

Important Note

Newton's second law, like the first law, is valid only in inertial reference frames, in the non-inertial reference frame of a car that begins accelerating, a cup on the dashboard starts sliding-it

accelerates- even though the net force on it is zero. Thus $\sum \boldsymbol{F} = \boldsymbol{ma}$ does not work in such an accelerating reference frame.

1.4 Newton's Third Law
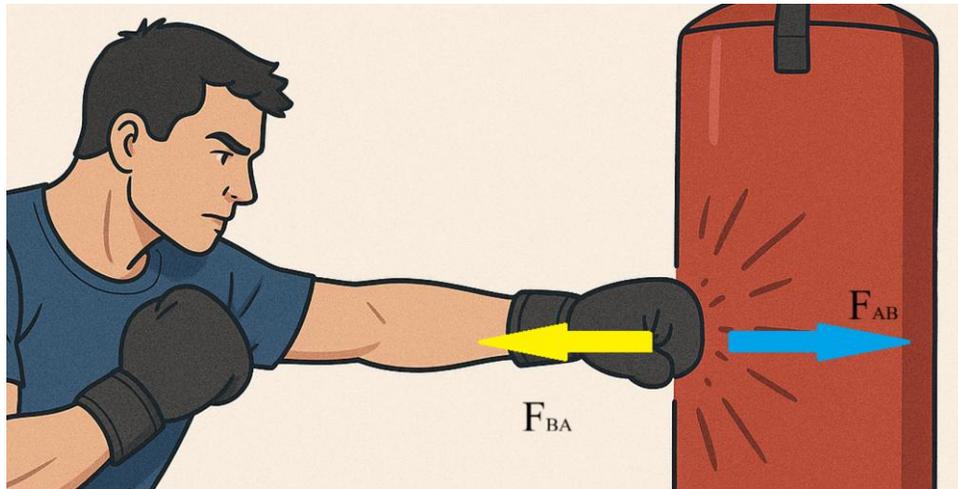
Newton realized that things are not so one-sided. True, the hammer exerts a force on the nail, but the nail evidently exerts a force back on the hammer as well, for the hammer's speed is rapidly reduced to zero upon contact. Only a strong force could cause such a rapid deceleration of the hammer. Thus, said Newton, the two objects must be treated on an equal basis.

If two objects interact, the force F_{AB} exerted by object A on object B is equal in magnitude and opposite in direction to the force F_{BA} exerted by object B on object A

"To every action there is an equal and oppo site reaction

The equation

$$F_{AB} = -F_{BA}$$

The two forces are called action and reaction, and either of the two forces can be action or reaction.

The two forces are equal in magnitude and opposite in direction.

Think: What is the sum of action and reaction forces, and why?

Results of Newton's third law:

forces always occur in pairs, or that a single isolated force cannot exist.

Check concept: When a computer monitor is at rest on a table, determine the forces acting on the monitor and the reaction to each one.

Think: if A large truck collides with a small racing car, which of them will be affected by more force

and why?

1.4.1   Normal Force

Definition: The force that the surface exerts on the object is placed on it

Direction: Perpendicular to the surface at the point of contact

Check concept: Find formula for calculating the normal force from weight and other forces in the following cases presuming that all surfaces are frictionless:
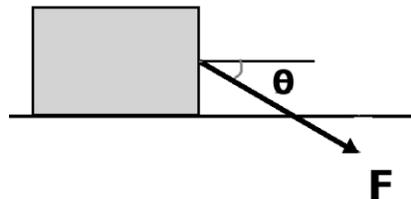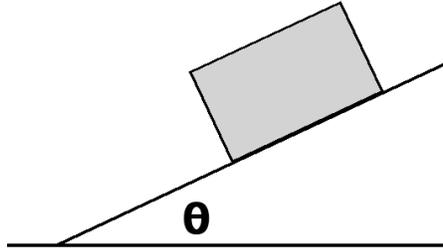
A box that is pushed down
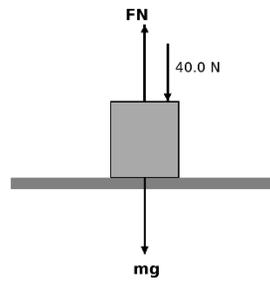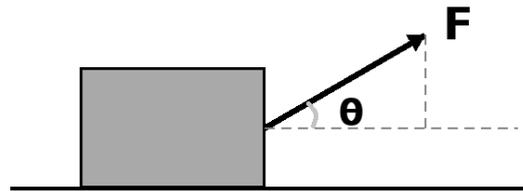
Object moving horizontally

Object moving horizontally

1.4.2   Elevator and Apparent weight

The person standing in the elevator is subjected to the influence of two forces: his weight mg and the reaction of the analog scale F_N. The analog scale measures the reaction F_N

Example 1-4

Find formula for calculating the apparent weight from the real weight in the following states:

a)   Elevator is static
b)   Elevator is moving at a constant speed.
c)   Elevator is accelerating up
d)   Elevator is accelerating down

$$Using: g = 9.8 \, m/s^2$$

a) Elevator static $(a = 0)$

$$N = W = mg$$

b) Elevator moving at constant speed $(a = 0)$

$$N = W = mg$$

c) Elevator accelerating up $(a > 0)$

$$W = N = m(g + a)$$

d) Elevator accelerating down $(a > 0$ downward$)$

$$W = N = m(g - a)$$

Note: If $a = g$ downward (free fall), then $N = 0$ (weightlessness).

Important Notes

- Solving problems of incline is usually easier if we choose the x-y coordinate system so the x axis points along the incline (the direction of motion) and the y axis is perpendicular to the incline.

-Force of gravity is not perpendicular to the slope, gravity acts vertically downward toward the center of the Earth

Guidelines for Solving Problems Using Newton's Second Law:

Follow this method when dealing with problems involving Newton's laws:

- Draw a simple and accurate diagram of the problem.

- Isolate the object whose motion you are analyzing. Draw a free-body diagram for this object. For systems containing more than one object, draw a separate free-body diagram for each object. Do not include in the diagram the forces exerted by the object on its surroundings. Establish appropriate coordinate axes for each object, then find the components of the forces along these axes.

- Apply Newton's Second Law in component form.

- Solve the component equations for the required unknowns and remember that you must have the same number of equations as the number of unknowns.

- Verify that your results are consistent with the diagram.

1.5 Applications for Newton's Laws:

1.5.1 Acceleration of Multiple-Body Systems:

Example 1-5

Three blocks are in contact on a smooth horizontal surface. Their masses are: $m_a = 2.0 \ kg, m_\beta = 7.0 \ kg, and \ m_c = 4.0 \ kg$. A horizontal force of 20 N acts on block $2.0kg$ to the right.

    a)   Find the acceleration of the system.

    b)   Determine the net force on each block.

    c)   Calculate the contact force between blocks A and B.

    d)   Calculate the contact force between blocks B and C.

Solve:

    a)   Newton's 2nd law on each block and then add the equations.

Label the contact forces: F_{AB}= force of B on A (or A on B), and F_{BC}= force of C on B (or B on C). Take right as positive.

Block A (mass m_A), horizontal forces: applied F to the right and contact F_{AB} to the left:

$$F - F_{AB} = m_A a. \qquad (1)$$

Block B (mass m_B), horizontal forces: F_{AB} to the right from A and F_{BC} to the left from C:

$$F_{AB} - F_{BC} = m_B a. \qquad (2)$$

Block C (mass m_C), horizontal force: F_{BC} to the right:

$$F_{BC} = m_C a. \qquad (3)$$

Now add (1) +(2) +(3):

$$(F - F_{AB}) + (F_{AB} - F_{BC}) + (F_{BC}) = m_A a + m_B a + m_C a.$$

On the left the internal contact forces cancel: $-F_{AB} + F_{AB} - F_{BC} + F_{BC} = 0.$ So,

Solve for a:

$$a = \frac{F}{m_A + m_B + m_C} = \frac{20}{2.0 + 7.0 + 4.0} = \frac{20}{13} = 1.54 \,\text{m/s}^2 \approx 1.5 \,\text{m/s}^2$$

b)   Net force on each block

$$F_{\text{net},A} = m_A a = 2.0 \times 1.54 = 3.08 \,\text{N} \approx 3.1 N$$
$$F_{\text{net},B} = m_B a = 7.0 \times 1.54 = 10.78 \,\text{N} \approx 11\text{N}$$
$$F_{\text{net},C} = m_C a = 4.0 \times 1.54 = 6.16 \,\text{N} \approx 6.2 N$$
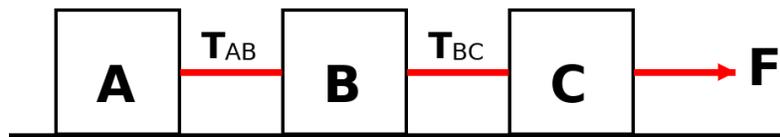
From (1) $F - F_{AB} = m_A a$

c)

$$F_{AB} = N_{AB} = (20 - 2 \times 1.54) = 16.9 \,\text{N}$$

d)

$$N_{BC} = m_C a = 6.2 \,\text{N}$$

Exercise 2: Study the following systems, write equations of applying Newton's second law for each object, and add the equations to get the equation of acceleration of the system.

1)   masses connected by ropes' mass is zero (or negligible), friction is negligible, A constant horizontal force F is applied.

2)   masses connected by ropes, ropes' mass is zero (or negligible), friction is negligible, the masses are pulled with a constant force T
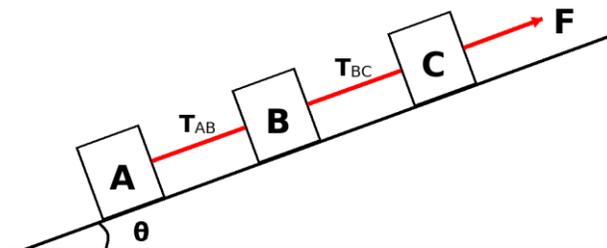
1.5.2 Smooth pulleys

A pulley is a wheel that rotates about a fixed axis, around which a rope or cord is wrapped. It is mainly used to change the direction of a force. When the pulley is smooth, the tension in the rope on both sides is equal in magnitude, since there is no energy loss due to friction or any conversion in the type of motion (for example, from linear to rotational).

Atwood machine: Two masses joined together by a light rope passing over a fixed, smooth, negligible mass pulley. The device is sometimes used in the laboratory to measure the free fall acceleration.
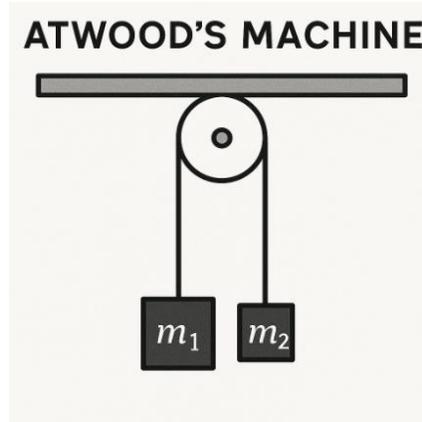
ATWOOD'S MACHINE

Example 1-6

Two masses m_1 and m_2 are connected by a light, inextensible string that passes over a frictionless, massless pulley, forming an Atwood's machine. Derive expressions for (a) the acceleration of the system and (b) the tension in the string.

- **Solution**

FREE BODY DIAGRAM
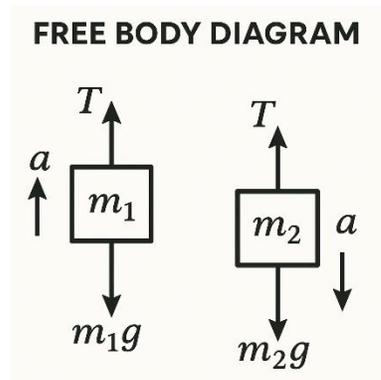
- Step 1: Analyze the forces

Each mass experiences two forces:

- Its weight (mg) acts vertically downward.
- The tension (T) in the string, directed upward.

Assume $m_2 > m_1$ so that m_2 moves downward and m_1 moves upward with the same magnitude of acceleration a.

- Step 2: Apply Newton's Second Law (net force = mass × acceleration)

For m_2:

$$m_2g - T = m_2a \qquad (1)$$

For m_1:

$$T - m_1 g = m_1 a \qquad (2)$$

- Step 3: Eliminate the tension T

Add equations (1) and (2):

$$(m_2 - m_1)g = (m_1 + m_2)a$$

Solve for a:

$$\boxed{a = \frac{(m_2 - m_1)g}{m_1 + m_2}}$$

Direction: The heavier mass (m_2) accelerates downward, and the lighter mass (m_1) accelerates upward.

- Step 4: Find the tension T

Substitute the expression for a into either equation (1) or (2).

Using equation (2):

$$T = m_1(g + a)$$

After substitution:

$$\boxed{T = \frac{2m_1 m_2}{m_1 + m_2} g}$$

Check

- If $m_1 = m_2$, then $a = 0$ (system in equilibrium).
- If $m_2 \gg m_1$, then $a \approx g$ (the heavier mass nearly falls freely).

Exercise 3: A block of mass M rests on a smooth horizontal table and is connected by a light, inextensible string that passes over a frictionless pulley to a hanging mass m, as shown in the figure.
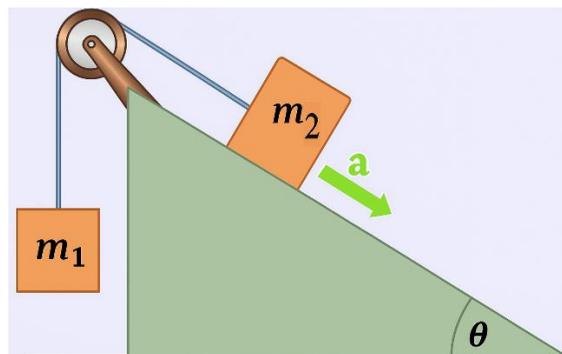
Find:

(a) the acceleration of the system,

(b) the tension in the string.
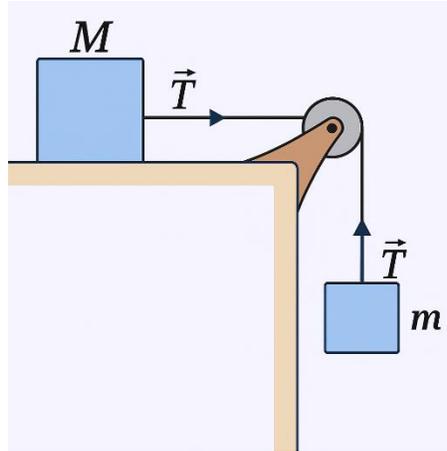
Exercise 4: Two blocks are attached by a lightweight cord that passes over a frictionless pulley of negligible mass, as in fig. Find:

(a) the acceleration of the system,

(b) the tension in the string.

1.6 Forces of Friction

We have neglected friction up to this point, even though taking it into account is necessary in most practical situations. Friction force originates primarily from electrostatic forces between contacting surfaces (the nature of electrostatic forces in solid materials is still not completely understood), or from collisions between the rough microscopic bumps on the two surfaces.

The direction of the friction force is parallel to the surfaces in contact and opposite to the direction of motion, or attempted relative motion, between them. To understand what happens in static and kinetic friction, let us consider the case of an object starting to move from rest:

We apply a force to move the object. The object does not move because of static friction. We increase the applied force, and the static friction force increases accordingly until it reaches its maximum value $f_{s\,max}$. If we increase the applied force beyond this point, the object begins to move, and kinetic friction appears—whose magnitude is less than the maximum static friction force.

1.6.1 Force of static friction

maximum Force of static friction:

$$f_{s\,max} = \mu_s\,F_N$$

μ_s: coefficient of static friction

1.6.2 Force of kinetic friction

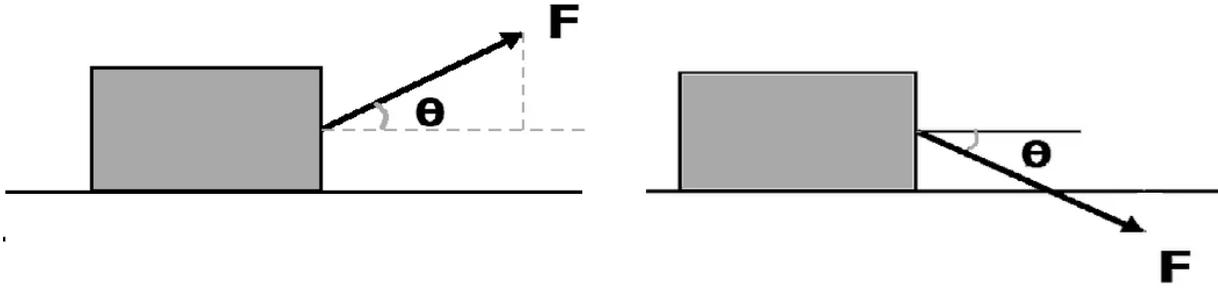Force of kinetic friction:

$$f_k = \mu_k F_N$$

μ_k : coefficient of kinetic friction

They are both without units, and their values are usually less than one. $\mu_k < \mu_s$

  Important Notes

coefficient of static friction μ_k is roughly independent of the sliding speed, as well as the area in contact.

Think: If you wanted to move an object, which of the two directions in the diagram would be easier to do with the same magnitude of force and the same θ?


Materials in Contact	Static Friction (μ_s)	Kinetic Friction (μ_k)
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.00	0.80
Wood on wood	0.25–0.50	0.20
Glass on glass	0.94	0.40
Waxed wood on wet snow	0.14	0.10
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.10	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

Example 1-7

A broken-down car of mass $1.0 \times 10^3 \ kg$ is on an icy driveway inclined at an angle 30.0°
   (a) Find the acceleration of the car, if the coefficient of kinetic friction is 0.10
   (b) Suppose the car slides from rest at the top of the incline, and the distance from the car's front bumper to the bottom of the incline is $d = 1.00 \times 10^2 \ m$. How long does it take the front bumper to reach the bottom, and what is the car's speed as it arrives there?
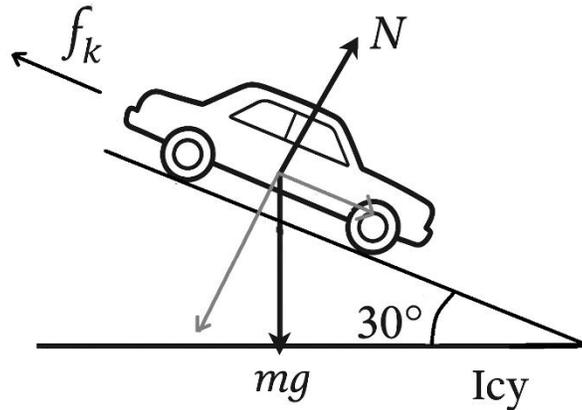
Given: $m = 1.0 \times 10^3$ kg, $\theta = 30.0°$, $\mu_k = 0.10$, $g = 9.80$ m/s^2.

(A) Acceleration

$$\text{Normal: } N = mg\cos\theta.$$

$$\text{Kinetic friction (up the slope): } f_k = \mu_k N = \mu_k mg\cos\theta.$$

Along the slope:

$$\Sigma F = mg\sin\theta - f_k = mg\sin\theta - \mu_k mg\cos\theta$$
$$a = \frac{\Sigma F}{m} = \frac{mg\sin\theta - \mu_k\, mg\cos\theta}{m} = g(\sin\theta - \mu_k\cos\theta) = (9.80\,\text{m/s}^2)(0.500 - 0.10 \times 0.866)$$
$$a = 4.05\ m/s^2 \approx 4.0\ m/s^2$$

(B) From rest, distance $d = 1.00 \times 10^2$ m $= 100$ m

$$d = \frac{1}{2}at^2$$
$$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2(100\,\text{m})}{4.05\,\text{m/s}^2}} \approx \boxed{7.0\ \text{s}}$$

Speed at the bottom:

$$v = \sqrt{2ad} = \sqrt{2(4.05\,\text{m/s}^2)(100\,\text{m})} \approx 28.5\ m/s$$

Note that we did not need the mass of the car in the solution.

Exercise 5: Two boxes connected by a cord. Two boxes, A and B, are connected by a lightweight cord and are resting on a smooth (frictionless) table. The boxes have masses of $12.0\ kg$ and $10.0\ kg$. A horizontal force F_p of $40.0\ N$ is applied to the $10.0kg$ box, as shown in Fig. Find (a) the acceleration of each box, and (b) the tension in the cord connecting the boxes.

A		B	$\vec{F_p}$
12,0 kg		10,0 kg	
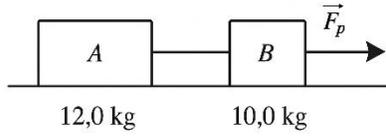
Exercise 6: A 10.0 kg g box is pulled along a horizontal surface by a force F_p of 40.0 N applied at a $30.0°$ angle above horizontal., and we assume a coefficient of kinetic friction of 0.30. Calculate the acceleration.

Exercise 7: Suppose a block is placed on a rough surface inclined relative to the horizontal. The incline angle is increased until the block starts to move. Show that by measuring the critical angle θ_c at which this slipping just occurs, we can obtain μ_s .

1.7 Additional problems

1- A 65-kg woman descends in an elevator that briefly accelerates at $0.20g$ downward. She stands on a scale that reads in kg. (a) During this acceleration, what is her weight and what does the scale read? (b) What does the scale read when the elevator descends at a constant speed of $2.0\ m/s$?

2- A person is trying to lift a crate upward at a constant speed and slowly, using a rope that passes around two pulleys: the upper pulley is fixed, and the lower pulley can move up and down as shown in the figure. What is the magnitude of the force F that the person must apply to the rope if the weight of the crate is 800 N?
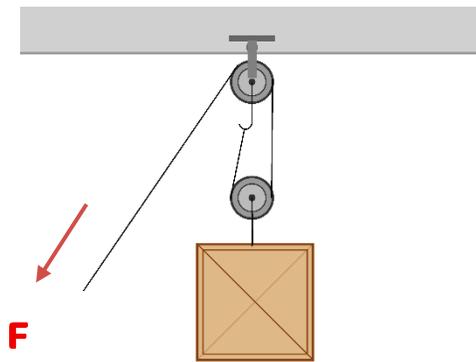

3- The skier has begun descending the 30.0° slope. If the coefficient of kinetic friction is 0.10, find:
   (a) Her acceleration.
   (b) The speed that will be reached after 4.0 s.

4- A $20.0\ kg$ box rests on a table. (a) What is the weight of the box and the normal force acting on it? (b) A $10.0\ kg$ box is placed on top of the $20.0\ kg$ box, determine the normal force that the table exerts on the $20.0\ kg$ box and the normal force that the $20.0\ kg$ box exerts on the $10.0\ kg$ box.

5- What average force is required to stop a $1100\ kg$ car in $8.0s$ if the car is traveling at $95\ km/h$?

6- A person stands on a bathroom scale in a motionless elevator. When the elevator begins to move, the scale briefly reads only 0.75 of her regular weight. Calculate the acceleration of the elevator and find the direction of acceleration.

7- Layla is to walk across a "high wire" strung horizontally between two buildings $10.0\ m$ apart. The sag in the rope when she is at the midpoint is $10.0°$, as shown in Fig. If her mass is $50.0\ kg$, what is the tension in the rope at this point?
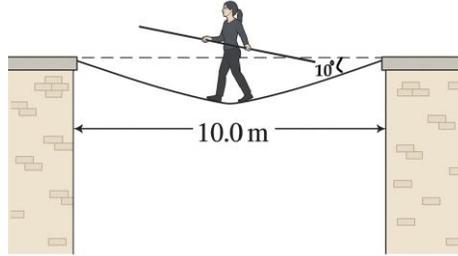

8- A ball is suspended by a string hanging from a car's rear-view mirror. What angle will the string make with the vertical while the car accelerates from rest at a traffic light to a speed of $18.0\ m/s$ in $6.0\ s$?
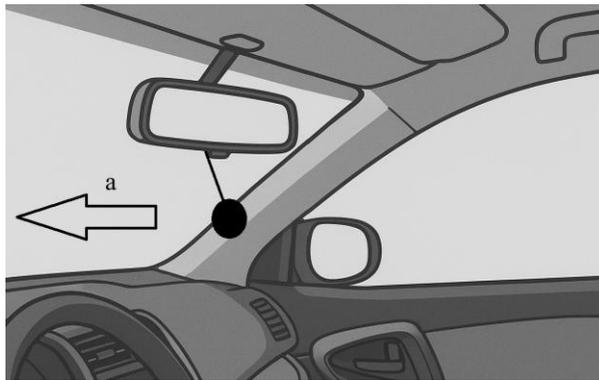

9- When the system in the figure is released, what is the maximum height the mass $2.5\ kg$ will reach, neglecting air resistance?
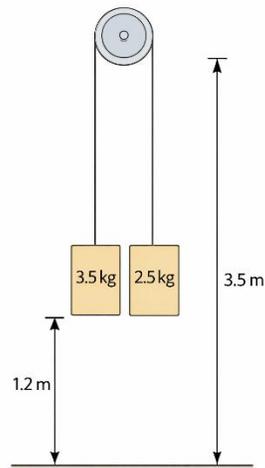
10- A person jumps from the roof of a house 3.9m high. When he strikes the ground below, he bends his knees so that his torso decelerates over an approximate distance of $0.70\ m$. If the mass of his torso (excluding legs) is $42\ kg$, find (a) his velocity just before his feet strike the ground, and (b) the average force exerted on his torso by his legs during deceleration.

11- In the drawing, the rope and the pulleys are massless, and there is no friction. Find (a) the tension in the rope and (b) the acceleration of each block.
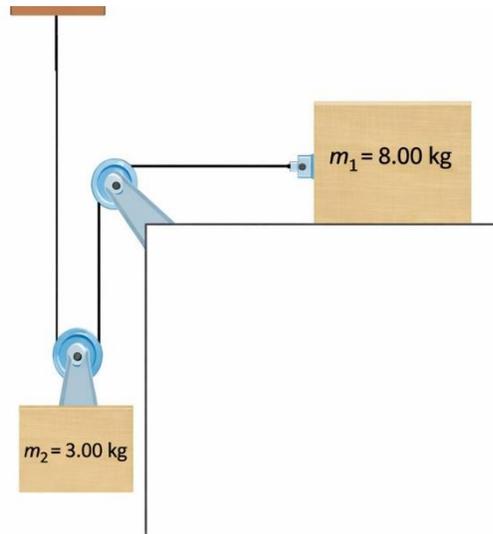
12- A $7.00 \times 10^2\ kg$ window-cleaning worker pulls himself upward using a machine (consisting of a pulley and a bucket), as shown in the figure.

(a) What force must he pull downward with to rise slowly at a constant speed?

(b) What is his acceleration if he increases the pulling force by 20%? Assume the total weight of the worker and bucket is $7.00 \times 10^2\ kg$.
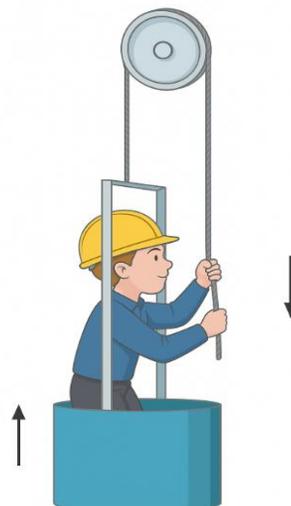
13- Three identical cubes are pulled as shown in the figure on a horizontal surface without friction. If the tension in the rope held by the hand is $30.0\ N$, what is the value of the tension in the other ropes?
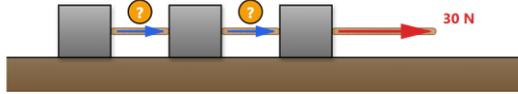
14- A motorcycle and a $60.0 - kg$ rider accelerate at $3.0\ m/s^2$ up a ramp inclined $10.0°$ above the horizontal. What is the magnitude of (a) the net force on the rider, and (b) The magnitude of the force exerted by the motorcycle on the rider.?

2 Circular Motion
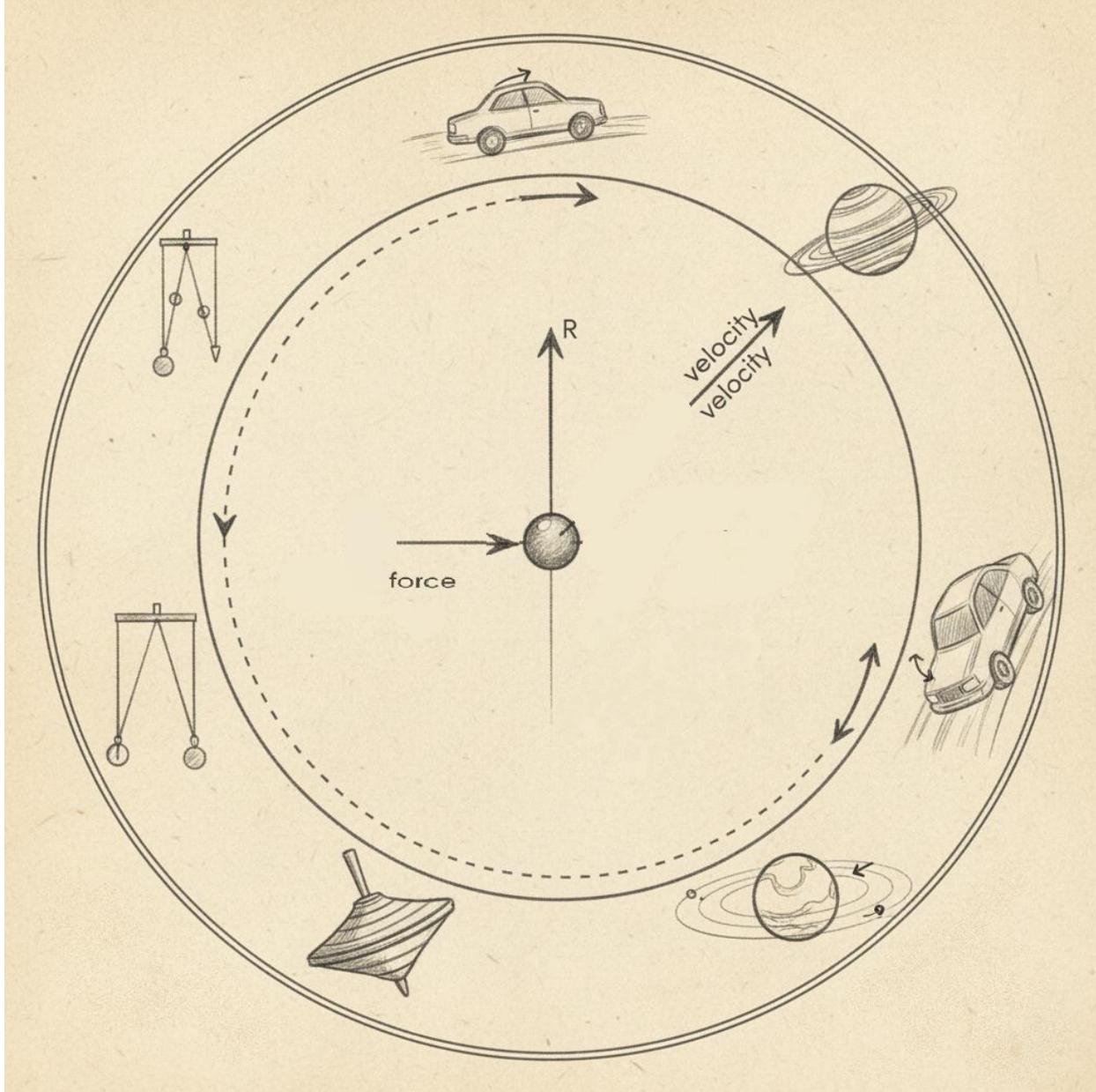
2.1 Uniform Circular Motion

We observe many circular motions in our daily lives, such as the movement of a car on a circular curve, the motion of the moon, a Ferris wheel, and others. These are examples of two-dimensional motion that we have learned about previously.

Motion of an object on a circular path of radius r with a tangential velocity v :constant of value and variable of direction.

2.1.1 Quantities of Uniform Circular Motion:

Tangential velocity (v):

It is always perpendicular to the radius of rotation.

Centripetal (or radial) acceleration (a_c):
It is always directed toward the center of the circle and is responsible for changing the direction of the velocity.

Centripetal force (F_c):
It is always directed toward the center of the circle and is responsible for producing the acceleration.
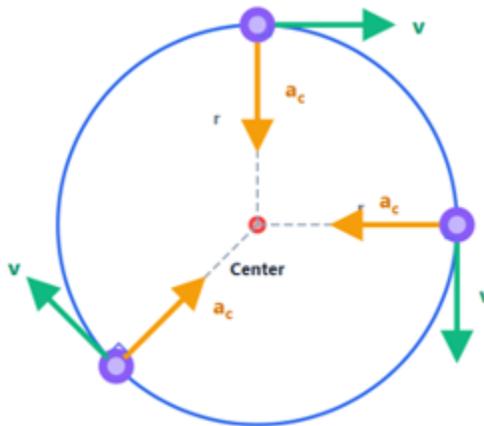
Periodic Time T:

The time required to complete one full revolution
It is measured in seconds (s) in the International System of Units (SI).

Frequency f:

The number of revolutions per unit time

It is measured in hertz (Hz), where one hertz equals one revolution per second:

$$Hz = rps$$

Laws of Uniform Circular Motion

$$a_c = \frac{v^2}{r}$$

$$F_c = ma_c = m\frac{v^2}{r}$$

$$f = \frac{1}{T} = \frac{v}{2\pi r}$$

$$T = \frac{2\pi r}{v}$$

$$v = 2\pi r f$$

Check concept: An object moves at constant speed along a circular path in a horizontal xy plane, with the center at the origin. When the object is at $x = -2m$, its velocity is $(-4\ m/s)\ j$. Give the object's (a) velocity (b) acceleration at $y = 2\ m$.

Example 2-1

The Moon's orbit around the Earth is roughly circular. With an average radius $3.84 \times 10^8 m$, the Moon takes 27.3 days to complete a complete revolution around the Earth. Calculate: (a) The average orbital velocity of the Moon. (b) Its perpendicular acceleration.

Solution:

Given Data:

$$Orbital\ radius, r\ =\ 3.84\ \times\ 10^8\ m$$
$$Orbital\ period, T\ =\ 27.3\ days\ =\ 27.3\ \times\ 24\ \times\ 3600\ =\ 2.35872\ \times\ 10^6\ s$$
$$(a)\ Average\ Orbital\ Velocity$$

$$v = (2 \times \pi \times 3.84 \times 10^8) / (2.35872 \times 10^6)$$
$$v = 1.023 \times 10^3 \, m/s \approx 1.02 \, km/s$$

(b) Perpendicular (Centripetal) Acceleration

$$a_c = v^2 / r$$
$$a_c = (1.023 \times 10^3)^2 / (3.84 \times 10^8)$$
$$a_c = 2.72 \times 10^{-3} \, m/s^2$$

Example 2-2

Identify the source of the centripetal force in each of the following cases:

(a) A car moving in a circular path around a roundabout.

(b) A stone tied to a string and swung horizontally (approximately parallel to the ground).

(c) Satellites orbiting the Earth.

Solution:

(a) The static friction force between the tires and the road surface.

(b) The tension force in the string.

(c) The gravitational force (mutual gravitational attraction).

Exercise 1: A tire 0.500 m in radius rotates at a constant rate of $2.00 \times 10^2 \, rev/min.$ Find the speed and acceleration of a small stone lodged in the tread of the tire (on its outer edge).

Exercise 2: Estimate the force a person must exert on a string attached to a $0.150 \, kg$ ball to make the ball revolve in a horizontal circle of radius 0.600 m. The ball makes 2.00 revolutions per second. Ignore the string's mass.
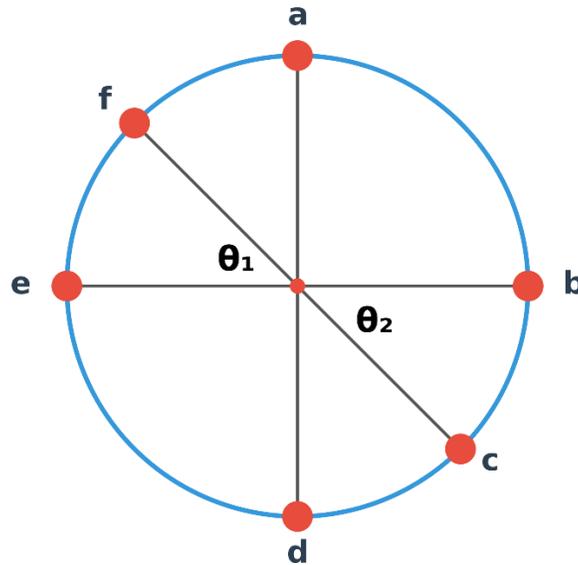
2.2 Vertical Circular Motion

It is the motion of an object in a vertical circular path, such as the motion of an object tied to a string, where a person rotates it with tension force T. The centripetal force is the resultant of forces in the radial direction (i.e., the weight and the tension force from the person), and therefore the centripetal force takes different values at different points. Remember that the centripetal force at any position is related to the object's speed by the relation

$$F_c = m\frac{v^2}{r}$$

Note: The centripetal force is not a separate force, but rather the net force in the radial direction.

Example 2-3

The figure shows the positions of a small ball attached to a light (massless) string, rotating in a vertical circular path. Write the centripetal force F_c in terms of the weight (or its components) and the tension at each position.

Solution: We calculate the magnitude of F_c for each position, and its direction is always towards the center of rotation.
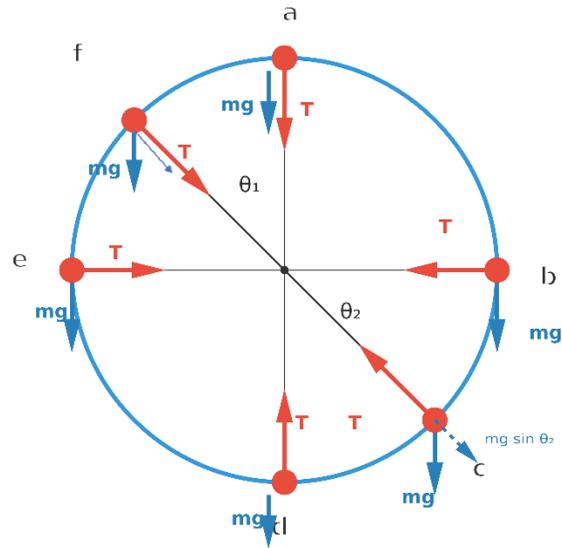
(a) $Fc = T + mg$
(b) $Fc = T$
(c) $Fc = T - mg \sin \theta_2$
(d) $Fc = T - mg$
(e) $Fc = T$
(f) $Fc = T + mg \cos \theta_1$

Example 2-4:

Find the minimum speed of an object moving in a vertical circular path.

Solution:

At the highest point, the minimum speed required for circular motion occurs when:

$$F_c = \frac{mv^2}{r} = mg$$
$$v_{min} = \sqrt{rg}$$

Concept Check:

What happens if the speed is less than $\sqrt{rg}$ for an object moving in a vertical circular path?

Concept Check:

Does the weight of the object affect the minimum speed of an object moving in a vertical circular path?

Exercise 3: A small ball of mass $0.200\ kg$ is attached to a $1.25\ m$ long light string and is whirled in a vertical circle.

(a) Determine the minimum speed the ball must have at the highest point of its path to maintain a taut string (i.e., so the ball continues in circular motion).

(b) If the ball is moving at three times the minimum speed found in part (a) when at the bottom of the circle, calculate the tension in the string at the bottom of the motion.

2.3 Nonuniform Circular Motion

$$\vec{a} = \vec{a}_r + \vec{a}_t$$
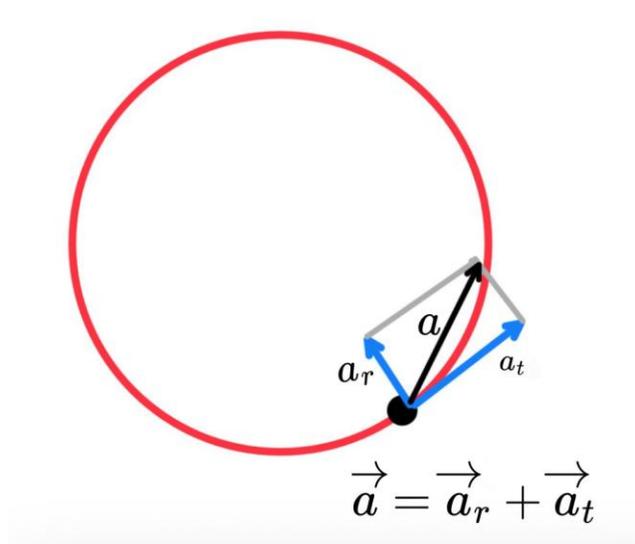
In non-uniform circular motion, the magnitude of tangential velocity changes as its direction changes, and in this case, the two perpendicular components of acceleration are the tangential component a_t and the perpendicular (radial) component a_r.

The tangential component a_t : Changes the value of velocity of an object and it is parallel to it.

When a_t is at in a direction of v? and when is it in reverse direction?

The radial component a_r : Changes the direction of velocity of an object and it is perpendicular to it.

The total acceleration

$$a = a_t + a_r$$

$$a = \sqrt{a_t{}^2 + a_r{}^2}$$

$$a_r = \frac{v^2}{r}$$

r: The radius of the path curve at the desired point

Consequently, two forces act on the body: a tangential force that produces the tangential acceleration, and a centripetal force that produces the radial (centripetal) acceleration.

Think: When circular motion is uniform, what is the value of F_t?

Example 2-5

A motorcycle travels over the top of a small hill. The hill can be approximated as the arc of a circle with a radius of $350\ m$. At the instant the motorcycle reaches the highest point of the hill, its speed is $8.0\ m/s$. At the same moment, the rider is accelerating forward along the road with a tangential acceleration of $0.450\ m/s^2$.

(a) Determine the magnitude of the normal (centripetal) component of the acceleration at this point.

(b) Find the magnitude of the total acceleration.

(c) State the direction of the total acceleration relative to the horizontal (give the angle below the horizontal).

Solution:

Given:

- Radius of the hill: r = 350 m
- Speed at the top: v = 8.0 m/s
- Tangential acceleration: a_t = 0.450 m/s²

(a) Calculate the normal (centripetal) acceleration:

The centripetal acceleration at the top is calculated using:

$$a_n = v^2/r$$

$$a_n = (8.0)^2\ /\ 350$$

$$a_n = 0.183\ m/s^2$$

(This acceleration is directed downward toward the center of the circle)

(b) Calculate the magnitude of the total acceleration:

The total acceleration is the vector sum of the tangential and normal accelerations:

$$a = \sqrt{(a_t^2 + a_n^2)}$$

$$a = \sqrt{[(0.450)^2 + (0.183)^2]}$$

$$a = 0.486 \, m/s^2$$

(c) Direction of the total acceleration:

The angle below the horizontal (θ) is calculated from:

$$\theta = tan^{-1}\left(\frac{a_r}{a_t}\right)$$

$$\theta = tan^{-1}\left(\frac{0.183}{0.450}\right)$$

$$\theta = 22.1°$$

Exercise 4: A small ball attached to a string of length $0.80m$ swings in a vertical circle. When the string makes an angle $\theta = 35°$ with the vertical, the speed of the ball is 2.2 m/s

    (a) Find the normal (centripetal) component of acceleration.

       (b) Find the tangential acceleration at that instant.

       (c) Determine the magnitude of the total acceleration and the angle it makes

       relative to the inward radial direction.

1- An astronaut on the surface of moon fires a cannon to launch an experiment package, which leaves the barrel moving horizontally. (a) What must be the muzzle speed of the package so that it travels completely around the moon and returns to its original location? (b) How long does this trip around the Moon take? Assume that the free fall acceleration on the moon is one-sixth that on the Earth and moon radius is $1740 \ km$

2- What is the magnitude of the Centripetal acceleration, of a pilot whose aircraft enters a horizontal circular turn with a velocity of: $v_i = (400i + 500j) \ m/s$ and $24.0 \ s$ later leaves the turn with a velocity of $v_f = (-400i - 500j) \ m/s$.

3- A $1.0 \times 10^3 \ kg$ car rounds a curve on a flat road of $5.0 \times 10^1 \ m$ radius at a speed of $14 \ m/s$. Will the car follow the curve, or will it skid? Assume: (a) the pavement is dry, and the coefficient of static friction is $\mu_s = 0.60$ (b) the pavement is icy and $\mu_s = 0.25$
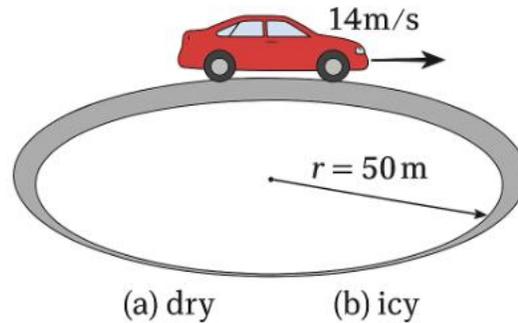
4- A small object of mass m is suspended by a string of length L and revolves at a constant speed in a horizontal circle of radius r. Find v in terms of L, g, and the sine and tangent of the angle θ.
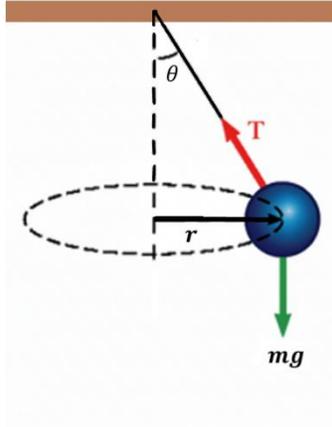
5- (a) What is the angle θ of banking for a road curve such that no friction is required for a car traveling at speed v around a curve of radius r? Find θ in terms of $v, r,$ and g.

(b) Calculate the banking angle of a curved road with a radius of 70.0 m that is designed for safe driving at a speed of 60.0 km/h.
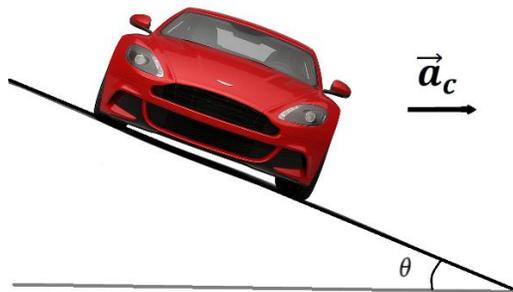
6- A high-speed tram enters a curved section of track and slows down from $72.0 \ km/h$ to $40.0 \ km/h$ in the $12.0 \ s$ it takes to travel through the curve. The radius of the track's curvature is $200 \ m$.

    (a) Determine the tangential acceleration of the tram during this interval, assuming the rate of slowing is constant.

    (b) At the instant the tram reaches 40.0 km/h, compute the centripetal acceleration.

    (c) Determine the magnitude of the total acceleration of the tram at this same instant.

1) A 5 kg object moves along a rough surface in a straight line, and its speed changes as shown in the diagram. If the object is moving under the influence of a horizontal tension force of 30 N, then the magnitude of the frictional force is:

A) 25N

B) 10N

C) 5N

D) 3N

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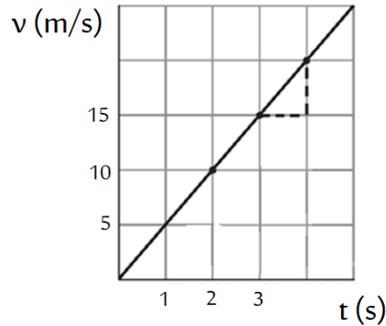
2) Which of the following facts correctly describes the concepts of mass and weight of an object?

A) The ratio between them at any point on Earth is 9.8

B) The ratio between them is equal to the ratio between them for another object placed in the same position.

C) These are two concepts that have the same meaning in physics but differ in their units.

D) They both express the magnitude of an object's inertia.

3) A net force f acts for 10 s on a body of mass 10^{-2} kg, initially at rest, after which the force ceases to act. The body traverses 0.5 m in the next 5 s with constant velocity. The magnitude of the force is:

A) 10^{-1} N

B) 10^{-2} N

C) 10^{-3} N

D) 10^{-4} N

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4) A body of mass 2.00 kg is moving towards west with a uniform speed of 4.00 m/s. A force of 4.00 N is applied to it towards north. The magnitude of the displacement of the body 4.00 s after the force is applied is:

A) 5.66 m

B) 16.0 m

C) 22.6 m

D) 32.0 m

----

5) The same uniform block is first placed on its long side, then on its short side, on the same inclined plane, as shown in the figure. The block accelerates down the inclined plane (Assume the box will not tip over). The magnitude of the block's acceleration in case (ii) compared to its acceleration in case (i) is:

(i)   (ii)
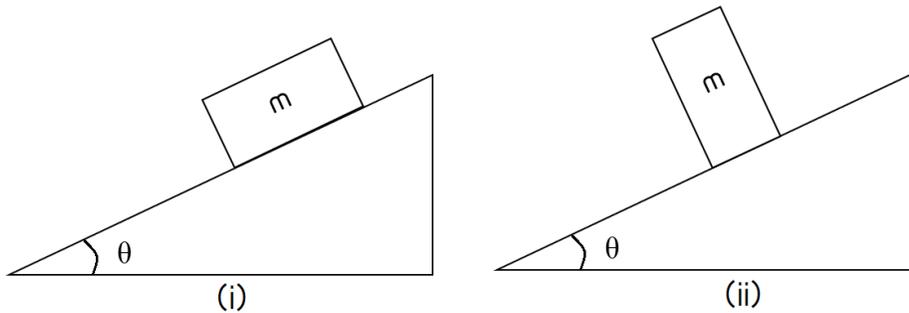
A) the same

B) greater

C) less

D) twice


6) A stone is moved in a horizontal circle with a radius of 1.50 m by a string suspended 2.00 m above the ground. The string breaks, and the stone flies horizontally, striking the ground 10.0 m horizontally

from the point where it left the circular path. The centripetal acceleration during circular motion is:

Consider g = 10.0 m/s²

A) 10.5 m/s²

B) 15.8 m/s²

C) 112.2 m/s²

D) 166.6 m/s²

----

7) A rotating ramp with a slippery surface allows a maximum speed of 13 m/s for cars. Cars exit the ramp onto an exit ramp with the same angle of inclination as the first ramp. If we want the second exit ramp to allow a maximum speed of 26 m/s, the radius of the first ramp must be changed to:

A) One quarter

B) One half

C) Two times

D) Four times

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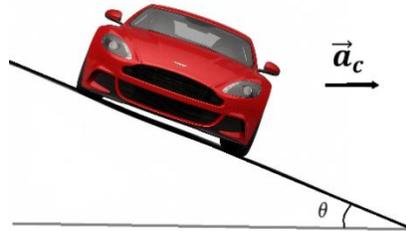
8) A stunt pilot of mass m flies an aircraft in a vertical loop maneuver. The aircraft travels in a circular path of radius 2.10 km at a constant speed of 240 m/s. Determine the force exerted by the seat on the pilot at:

   (a)   The lowest point of the loop.
   (b)   The highest point of the loop.

Question	1	2	3	4	5	6	7	8
Answer	C	B	D	C	A	D	D	**a**-$3.80mg$, **b**- $1.80mg$.

FINAL ANSWERS

Chapter 1:

1- $[ML^{-1}T^{-2}]$. **2-** $T \propto L^{\frac{1}{2}} \times g^{-\frac{1}{2}}$, $T \propto \sqrt{\frac{L}{g}}$. **3-** B. **4-** B.

Chapter 2:

1a- 12.6 km/h at 71.6° north of east. **1b-** minutes. **2a-** 19.5° west of north. **2b-** 13.3 minutes. **3a-** 261 km/h. **3b-** 15.3° south of east. **4-** 866 km/h. **5-** 2.92 m/s, 7.9° above the east direction.

Chapter 3:

Exercises: **1-** $a = (29.3\hat{\imath} - 1.88\hat{\jmath})m/s^2$. **2a-** $a = \frac{F}{m_A+m_B+m_C}$ **2b-** $a = \frac{F-(m_A+m_B+m_C)g\sin\theta}{m_A+m_B+m_C}$. **3a-** $a = \frac{mg}{m+M}$. **3b-** $T = \frac{Mmg}{m+M}$. **4a-** $a = \frac{(m_1-m_2\sin\theta)g}{m_1+m_2}$. **4b-** $T = \frac{m_1m_2g(1+\sin\theta)}{m_1+m_2}$. **5-** $a = 1.82$m/s², **5b-** $T = 21.8$N. **6-** $a = 1.12$m/s². **7-** $\mu_s = \tan\theta_c$.

Additional problems: **1-** Weight = 637 N; Scale reads 510 N or 52 kg. **2-** 400N. **3a-** m/s² down the slope **3b-** $v = 16.2$m/s **4a-** Weight = 196 N (down); Normal force = 196 N (up) **4b-** 294 N, 98N. **5-** 3.63×10^3 N. **6-** 2.45 m/s² downward. **7-** 1.41×10^3 N. **8-** 17.0° (backward). **9-** 2.6m. **10-** 2.7×10^3N (upward) **11a-** $a_1 = 1.68\ m/s^2$, $a_2 = 0.840\ m/s^2$ **11b-** 13.4N. **12a-** 350N **12b-** 1.96 m/s² **13-** 20N,10N. **14a-** 180N , **14b-** 644N

Chapter 4:

Exercises: **1-** 219m/s, 219 m/s². **2-** 14.2 N. **3a-** 3.50m/s, **3b-** 19.6N. **4a-** 6.05 m/s², **4b-** 5.62 m/s², **4c-** 8.26 m/s², $\phi \approx 43°$

Additional problems: **1-** 1684 m/s, 1 hour 48 minutes. **2-** $a_c = 83.8\ m/s^2$ **3a-** $F_c = 3920N, f_{smax} = 5880N$ so no skid. **3b-** $F_c = 3920N, f_{smax} = 2450N$ so the car will skid. **4-** $v = \sqrt{gL\sin\theta\tan\theta}$. **5a-** $\tan\theta = \frac{v^2}{gr}$, **5b-** 22°. **6a-** $0.74m/s^2$, **6b-** $0.62m/s^2$, **6c-** $0.96m/s^2$.

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